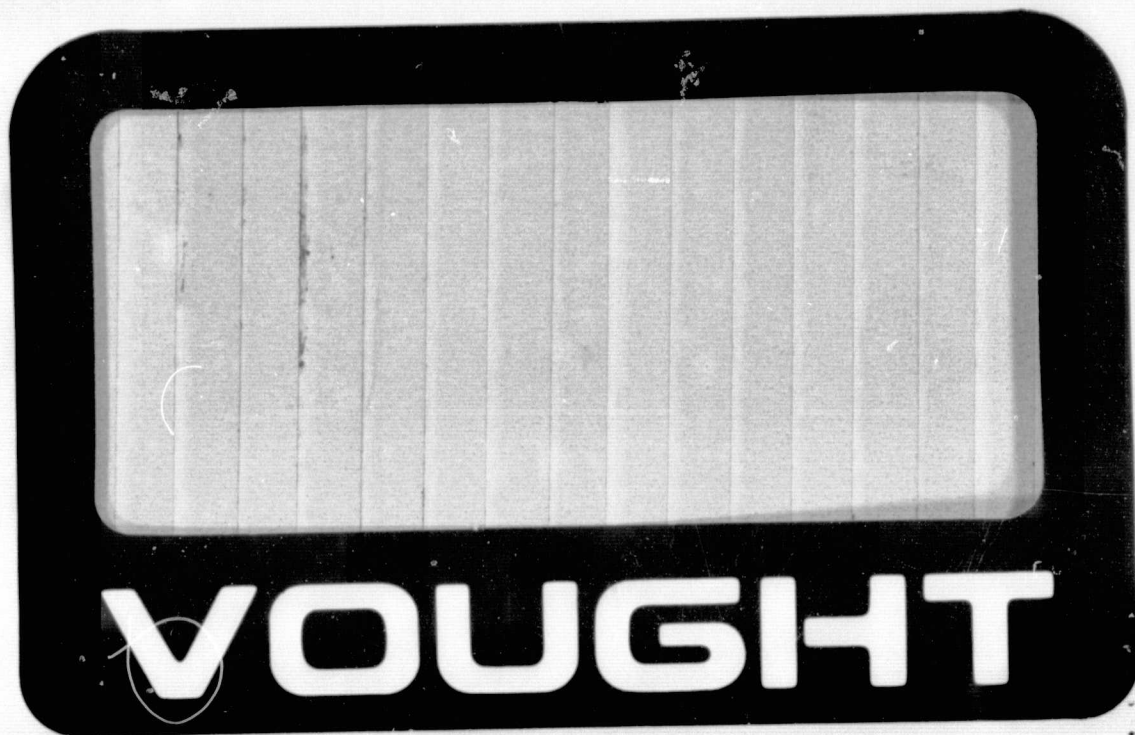


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CR-151679



(NASA-CR-151679) SPACE SHUTTLE I-TUBE
RADIATOR TESTING AT JOHNSON SPACE CENTER,
MAY 1976, VOLUME 1 Final Report (Vought
Corp., Dallas, Tex.) 94 p HC A05/MF A01

N78-22142

Unclas
CSCL 22A G3/16 15636



FINAL REPORT

SPACE SHUTTLE I-TUBE RADIATOR TESTING
AT JOHNSON SPACE CENTER - MAY 1976

REPORT NO. T169-65

VOLUME I

DECEMBER 23, 1976

Prepared Under Contract NAS 9-14907

for

NASA JOHNSON SPACE CENTER

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REFERENCES

1. Hixon, C. W., "I-Tube Radiator Panel Flow Instability Investigation", Vought Corporation Test Report No. 224TR016, 16 April 1976.
2. Phillips, M. A., "Space Shuttle L-Tube Radiator Testing at Johnson Space Center", Vought Corporation Report No. T169-67, 23 December 1976.
3. Scheps, P. B., "Space Shuttle Cavity Assessment Test Program", Vought Corporation Report No. T169-66, 31 December 1976.
4. Howell, H. R., "Orbiter Space Radiator Absorbed Heat Handbook", Vought Corporation Report No. 224RP0052, 29 September 1976.

1.0 INTRODUCTION

1.1 Summary

This report documents two weeks of thermal vacuum testing conducted jointly by NASA Crew Systems Division, Rockwell International (RI) and the Vought Corporation. The testing was accomplished between May 3 and May 21, 1976, and was intended to verify the design of the Space Shuttle I-tube radiator panels.

During the two weeks of testing a representative forward (two-sided) panel was successfully operated in a variety of simulated environmental conditions. Performance limits for both high and low load operations were established. Confidence in the stable operation of the panel throughout its typical operating range was verified by the testing, and design studies were conducted to analyze the effects of the payload bay door, and the panel deployment angle, on performance.

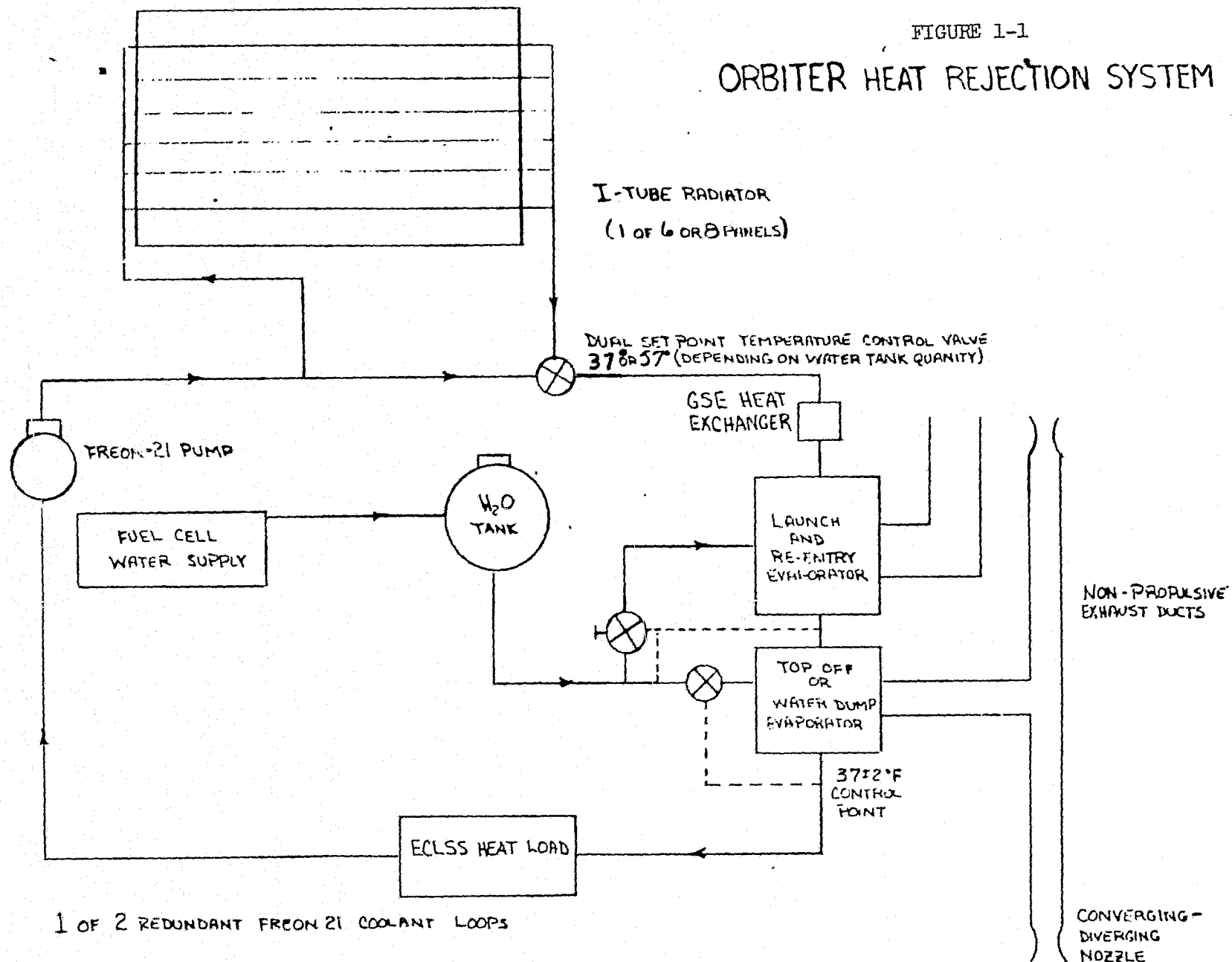
Section 2.0 of this report discusses the detailed test objectives. Section 3.0 contains a description of the test article, followed by a summary of test operations in Section 4.0. Section 5.0 discusses results in three parts: environments, performance studies, and special design studies. Finally, conclusions are presented in Section 6.0.

1.2 ORBITER HEAT REJECTION SYSTEM DESIGN

The operational OHRS will consist of three devices to reject the heat loads both internally generated and absorbed from the environment; namely, space radiators, water flash evaporators, and an ammonia boiler. Supplemental heat rejection capability will be provided on the ground by a Ground Support Equipment (GSE) heat exchanger.

During on-orbit operation, heat rejection will be accomplished primarily by the space radiators, supplemented by water evaporation through the FES (Figure 1-1). The orbiter radiator configuration consists of 6 or 8 panels to be mounted to the payload bay doors as shown in Figure 1-2. The two forward panels on each side are to be deployed away from the doors to increase the heat rejection capacity. Freon flow to the panels will be regulated by two downstream temperature control valves (one per loop). The valves will bypass a portion

FIGURE 1-1
ORBITER HEAT REJECTION SYSTEM



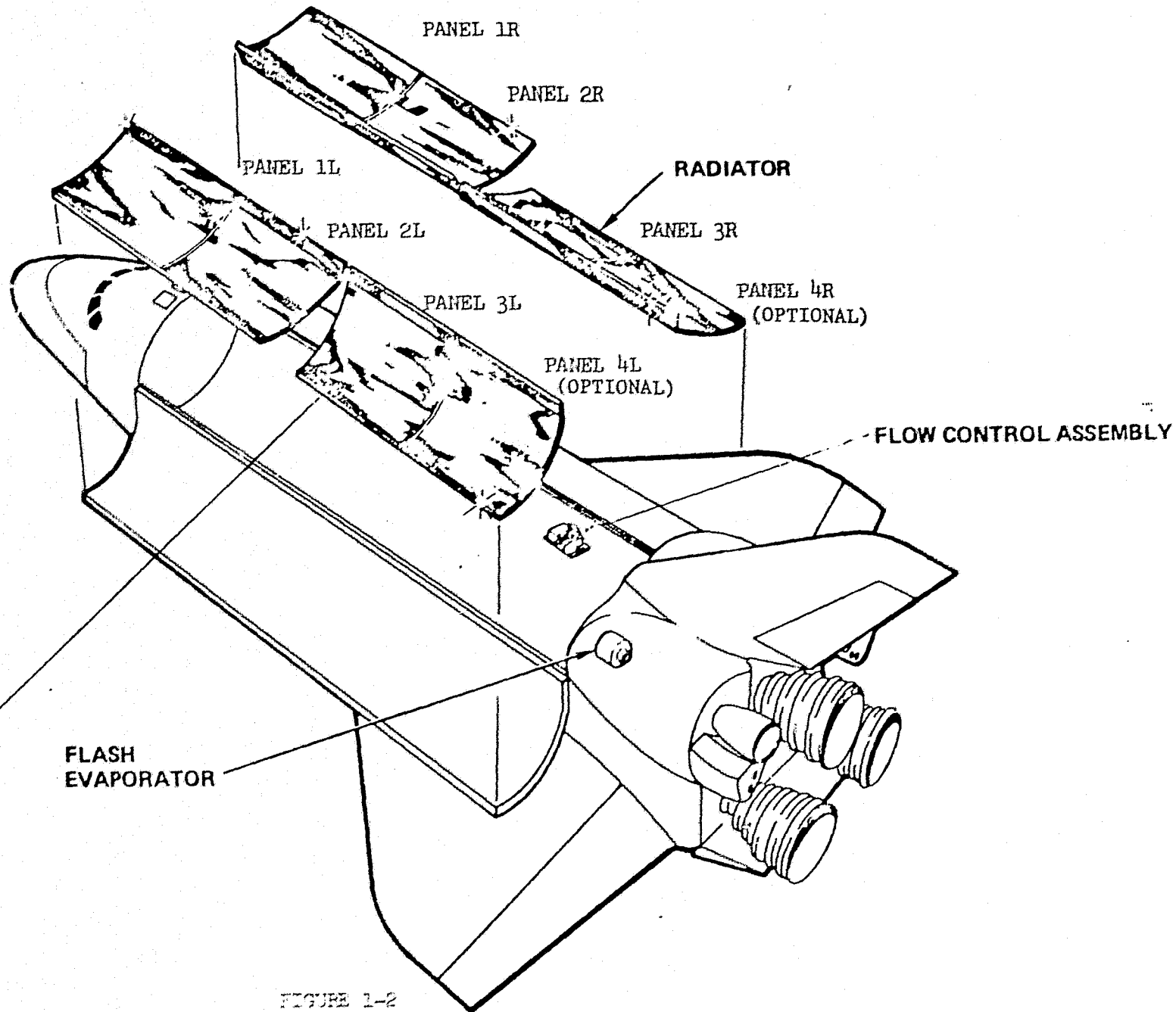


FIGURE 1-2
SPACE SHUTTLE ORBITER RADIATOR CONFIGURATION

of the flow to regulate the radiator outlet temperature to either of two temperature set points (38°F and 58°F). The set point temperature will depend upon the quantity of water in the fuel cell water storage system. As excessive water accumulates in the holding tank the set point will be increased to 58°F, thereby reducing the amount of heat rejection from the radiators. Water evaporated in the flash evaporator top-off section will lower the freon temperature to 37+2°F until the holding tank level decreases, at which time the control valve will be reset to 38°F. Should on-orbit heat loads increase such that the radiator outlet temperature cannot be maintained at 38+2°F with total freon flow (no bypass flow), the flash evaporator will activate as necessary to control the temperature of the freon supplied to the vehicle at 37°F. The water is ejected from the flash evaporator through a set of non-propulsive sonic nozzles to minimize the particle and gas contamination of the space environment surrounding the orbiter.

In addition to providing supplemental heat rejection capacity during on-orbit operation, the FES will provide the sole means of heat rejection for the orbiter above an altitude of 140,000 feet during ascent and above 100,000 feet during reentry. Below 100,000 feet the ammonia boiler is activated to provide cooling during reentry and through the post landing phase.

1.3 Previous Test History

Two series of development tests have been conducted in support of the Shuttle program. The first testing was accomplished in 1973 and consisted of a set of eight flat "U-tube" panels operative together with a flash evaporator, and regulated via a single control valve. Impulse signals sent to the control valve were generated by a water tank level sensor which simulated a typical fuel cell water generation profile. The test verified the overall validity of an integrated heat rejection system.

The second series was initiated in March 1975 and encompasses six different tests, tabulated in Table 1-1. The final test in this series is the subject of this report.

Initial testing in this series concentrated on panel-to-PBD cavity characteristics. A full-size cavity simulator was constructed and covered with flight-type silver/teflon coating. The test article was exposed to solar and IR environments and exchange factors and absorbed heats were calculated. Subsequent testing measured thermal performance of a two-panel contoured flowing L-tube radiator system, including a PBD simulator installed to create a 38 degree cavity angle with the forward panel. The thermal performance testing was expanded to include cavity angles of 50 and 70 degrees. The later testing was conducted in parallel with the Self-Contained Heat Rejection Module (SHRM) test.

TABLE 1-1
RADIATOR TEST PROGRAM - MARCH 1975 THROUGH MAY 1976

CHAMBER (Date)	TEST DESCRIPTION	REMARKS
B (Mar 75)	Cavity Assessment Solar Tests	Non-flowing panel and PBD simulator tested in solar environment. Script F's, cavity effective absorbtivity, and total absorbed heat loads measured experimentally.
A (May 75)	Cavity Assessment IR Test	Non-flowing panel and PBD simulator tested in quartz lamp environment. IR lamps calibrated, and cavity effective emissivity and total absorbed heat loads measured experimentally.
A (Aug 75)	38 Degree Cavity Thermal Performance Test	Aft and forward flowing L-tube radiator panels tested in series. Panel-to-PBD cavity angle set at 33 degrees. Instrumented to measure thermal performance and thermally induced structural distortion and strain. (Additional non-flowing panel tested to assess coating suitability.)
A (Oct 75)	Wide Cavity Thermal Performance Test	Forward flowing radiator L-tube panel test. Panel-to-PBD cavity angles set to 50 and 70 degrees. Instrumented to measure thermal performance and thermally induced strain.
VOUGHT (Feb 76)	I-Tube Flow Stability	Prototype forward I-tube panel without payload bay door. Cold-wall(LN ₂) environment only.
B (May 76)	I-Tube Performance Test	Prototype forward I-tube panel with payload bay door simulator. Two values of panel deployment angle tested. Solar simulation at 77° sun angle. Quartz lamp array for IR flux simulation.

TEST OBJECTIVES

The purpose of this test was to establish the thermal performance characteristics of the forward I-tube radiator panel over a wide range of operational flowrate and temperature conditions while subjected to both solar and IR environments.

Of prime importance is establishing the effects of the payload bay door (PBD) on I-tube radiator performance. The thermal interaction between the panel and PBD could result in flow stability problems under extreme environment conditions. Also, the specular characteristics of the panel and PBD coating material will result in high localized temperature peaking that could adversely affect the radiator heat rejection capacity.

The test was conducted in two phases; the first phase subjecting the test article cavity to solar radiation while simultaneously applying IR energy to the top surface of the radiator panel to simulate on-orbit absorbed flux, and the second phase subjecting the test article to controlled IR environments only. The specific test objectives include the following:

- a. Determine cavity specularity and skewed environment effects on radiator thermal performance
- b. Investigate fluid flow stability with radiator panel mated to PBD
- c. Determine radiator high heat load performance
- d. Determine radiator low heat load performance
- e. Evaluate silver teflon coating performance, and
- f. Provide data for analytical model verification

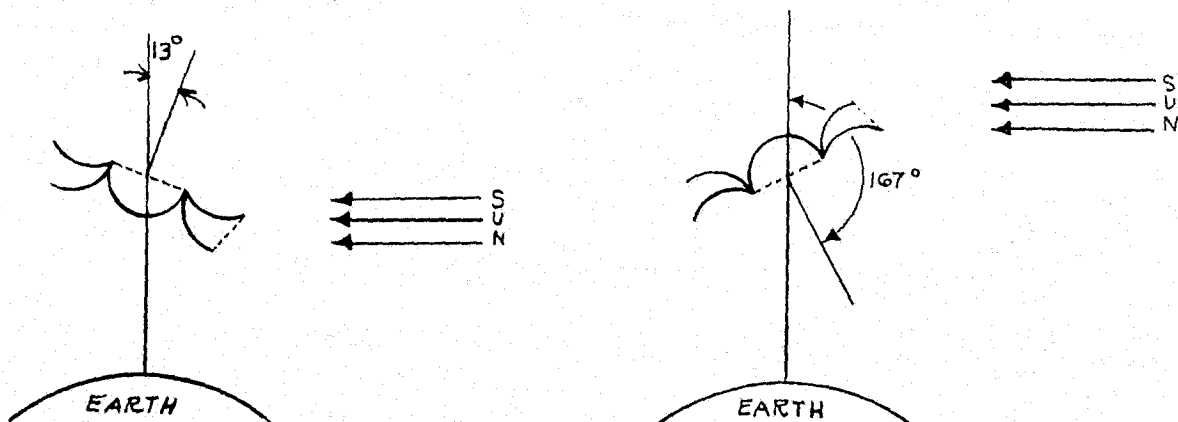
2.1 CAVITY SPECULARITY AND SKEWED ENVIRONMENT EFFECTS

The specular reflecting characteristics of the silver Teflon coating result in a focusing effect in the cavity formed by the panel and PBD. The area, along the length of the panel, to which the radiant energy is concentrated will experience substantially higher temperatures than surrounding areas of the panel, thus possibly reducing the overall panel heat rejection capability.

The location of the "hot spot" produced by focusing is a function of the incident sun angle at the cavity plane. Previous testing has established the sun-to-cavity angle which causes the worst case hot spot, an angle which would occur in space at the following orbital conditions.

- a. $\beta = 90^\circ$, X on V, earth oriented, roll = 167°
- b. $\beta = 90^\circ$, X on V, earth oriented, roll = 13°

The following diagrams illustrate these orbital situations. In both cases shown, the angle between the sun and the cavity plane is the same -- only the IR and albedo flux is different between the two cases.



Other inertial orbits are possible which provide maximum solar trapping. The two cases pictured represent high (167° roll) and low (13° roll) levels of IR flux due to the position of the earth relative to the radiator.

The first on-orbit attitude listed above approximates a worst hot case environment in which there is solar flux in the cavity and a high IR heat load from the earth on the radiator top surface. The second on-orbit attitude results in solar flux in the cavity while the radiator top surface views deep space, thus producing a condition that should yield near maximum thermal gradients from top to bottom surface of the panel.

These on-orbit conditions have been analytically evaluated to determine the solar and IR absorbed flux to be applied to the radiator top surface simultaneously with the solar flux. Once the environments are known for each attitude, the appropriate radiator inlet temperatures and flowrates can be analytically determined for both 6 and 8 panel configurations to define the test point conditions. The test results should be indicative of I-tube performance under realistic skewed environment conditions which include the cavity specular effects.

2.2 FLUID FLOW STABILITY (WITH PBD MATED TO PANEL)

Parallel tube flow systems such as the I-tube panel can possibly experience fluid flow stability problems under certain extreme operating conditions. The identical I-tube radiator panel was used in a flow stability test at Vought/Dallas (Reference 1) prior to shipment to JSC. During test buildup at JSC, the panel was mated with a PBD simulator (used in previous I-tube radiator testing, Ref. 2). Radiator performance was monitored throughout

the I-tube test (both solar and IR environments) to detect any measurable influence of the PBD on fluid flow stability.

2.3 HIGH HEAT LOAD THERMAL PERFORMANCE

The Shuttle operational radiator system will be required to reject high heat loads under certain on-orbit conditions. The I-tube panel was tested over a wide range of simulated heat loads and external environment conditions to permit parametric evaluation of the panel performance and to establish the maximum heat load capacity. During the high load test sequence, selected test conditions were imposed on the I-tube panel to duplicate conditions provided for the L-tube panel in a previous test (Reference 2) for radiator configuration performance comparison.

A secondary objective during the high load performance mapping was to monitor the temperature differential between the transport tube and panel facesheets (six locations). This data will aid in verifying that the thermal resistance of the adhesive layer between the tubes and facesheets for a full size panel is comparable to smaller specimen test results.

2.4 LOW HEAT LOAD THERMAL PERFORMANCE

As the internal heat rejection requirement for the Shuttle decreases, the radiator flow control system is designed to divert increased amounts of the freon flow from the radiators to the system bypass lines. Radiator temperatures decrease sharply as a result of the lower flowrates. Low load performance mapping is necessary to determine the lowest possible heat load that can be accommodated without freezing of the fluid in the panels.

2.5 RADIATOR COATING PERFORMANCE

The radiator panel and PBD surfaces will have silver teflon coatings that provide the low solar absorptance/IR emittance ratio required for high heat rejection performance. The coating adhesive on the I-tube panel was cured by a different process than was used on previous test panels. The cure process involves temperature and pressures greater than atmosphere in an autoclave. Also, a portion of coating was pre-outgassed before application. The test article was visually monitored throughout the test to assess coating performance under test environment conditions.

2.6 ANALYTICAL MODEL VERIFICATION

Vought and Rockwell International have recently developed detailed thermal models for the analytical assessment of the OHRS performance with I-tube radiators. One of the key test objectives was data gathering suitable for establishment of reasonable confidence levels in analytical model predictions.

3.0 TEST ARTICLE DESCRIPTION

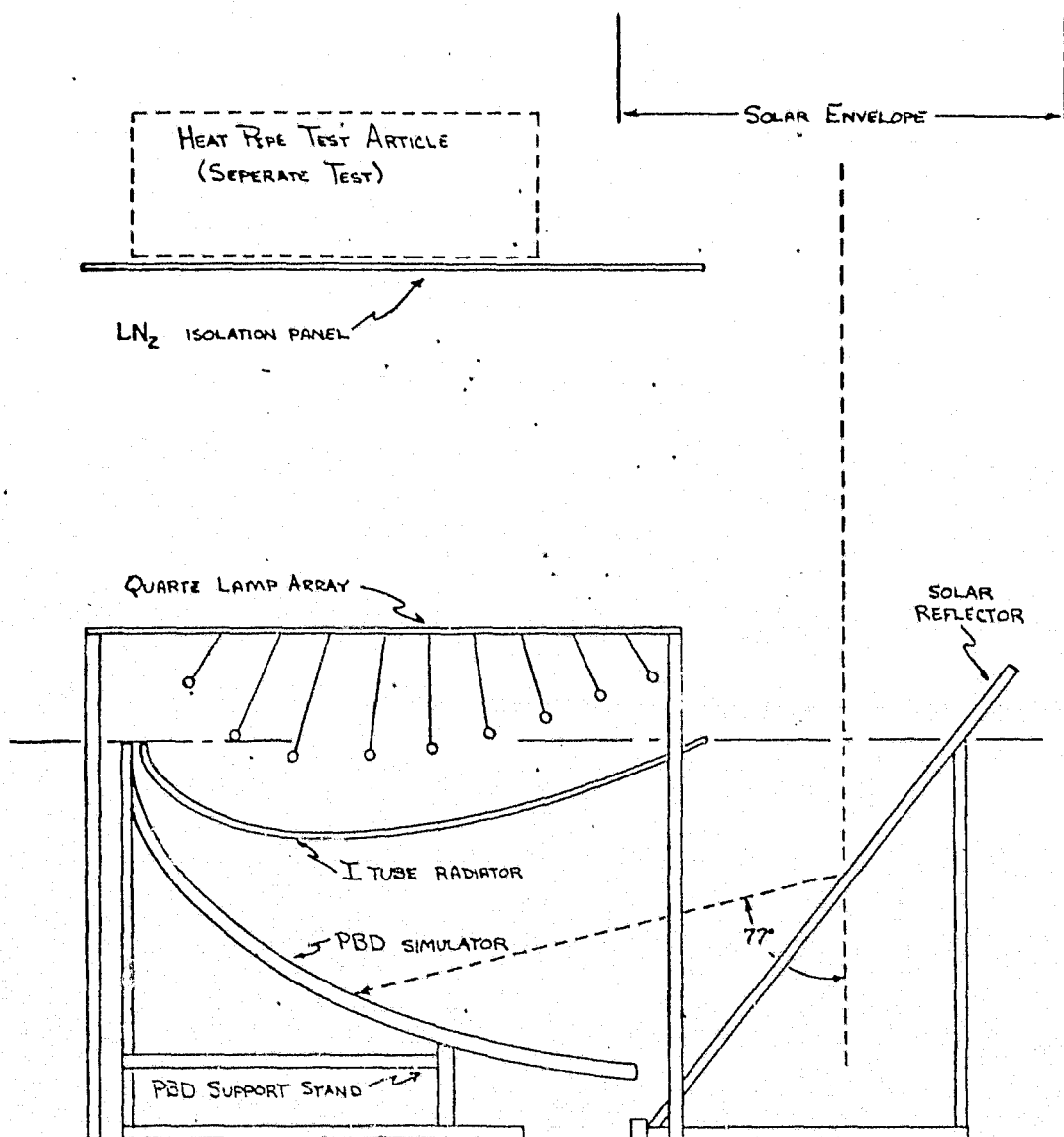
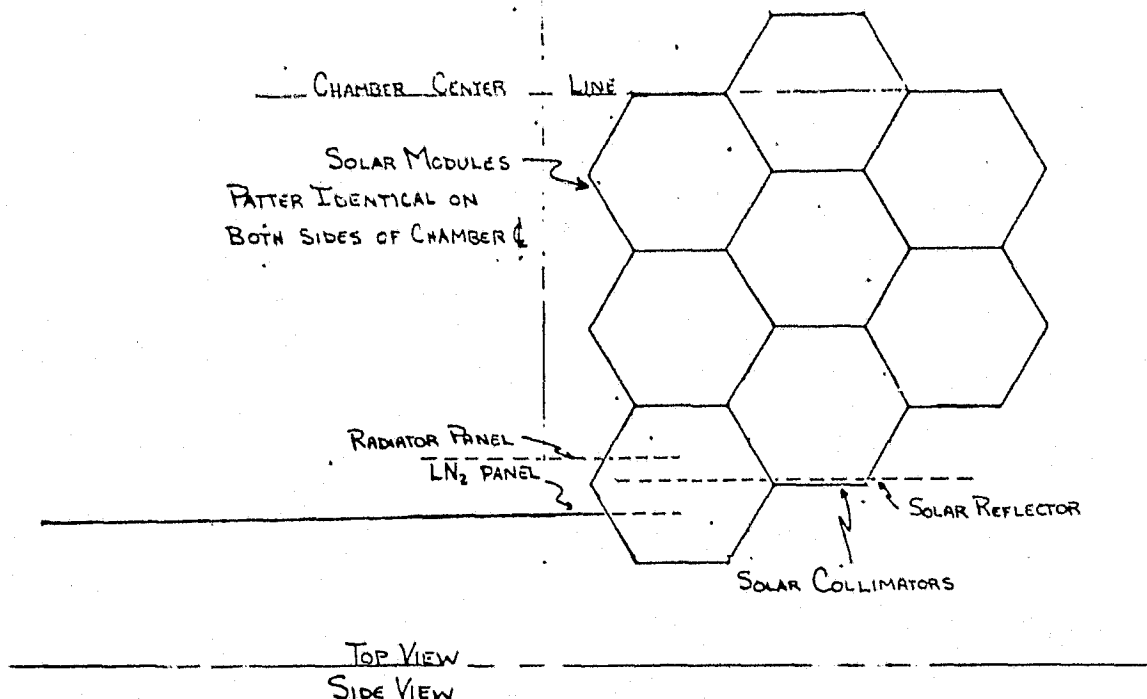
3.1 CHAMBER LAYOUT

The test article is a Shuttle representative I-tube forward radiator panel which was subjected to a thermal vacuum environment and selected operating conditions expected during earth orbital flight. A PBD simulator was incorporated into the test setup to define the cavity formed by the door and panel. IR flux on the radiator top surface was simulated by a quartz lamp array. Simulated solar flux was directed into the cavity at a 77 degree angle by means of a mirror. Figure 3-1 is a diagram of the test setup, while Figures 3-2 through 3-5 are photographs taken in the chamber prior to testing. A cluster of three liquid nitrogen panels were installed above the quartz lamps to provide thermal isolation between the panel and an independent heat pipe test article, being tested separately.

A flow bench provided the desired Freon-21 flow rates and inlet temperatures to the panel. The system was designed to allow the freon to enter and exit the panel through either the end or the middle manifold connections, although only the end feed was used in the current testing.

3.2 TEST PANEL

The test panel is thermally representative of the anticipated flight hardware. The panel consists of an aluminum honeycomb core bonded between aluminum facesheets with a contour approximating the shape of the number 2 (mid forward) panel on the Orbiter configuration (see Figure 1-2). Round tubes are bonded to the inside surface of both facesheets. The tubes are embedded in the honeycomb core to provide a smooth external surface for applying the silver teflon coating. Figure 3-6 summarizes the panel design. Vought drawing 224GT0100 contains additional details.



CHAMBER VIEW OF TEST SETUP

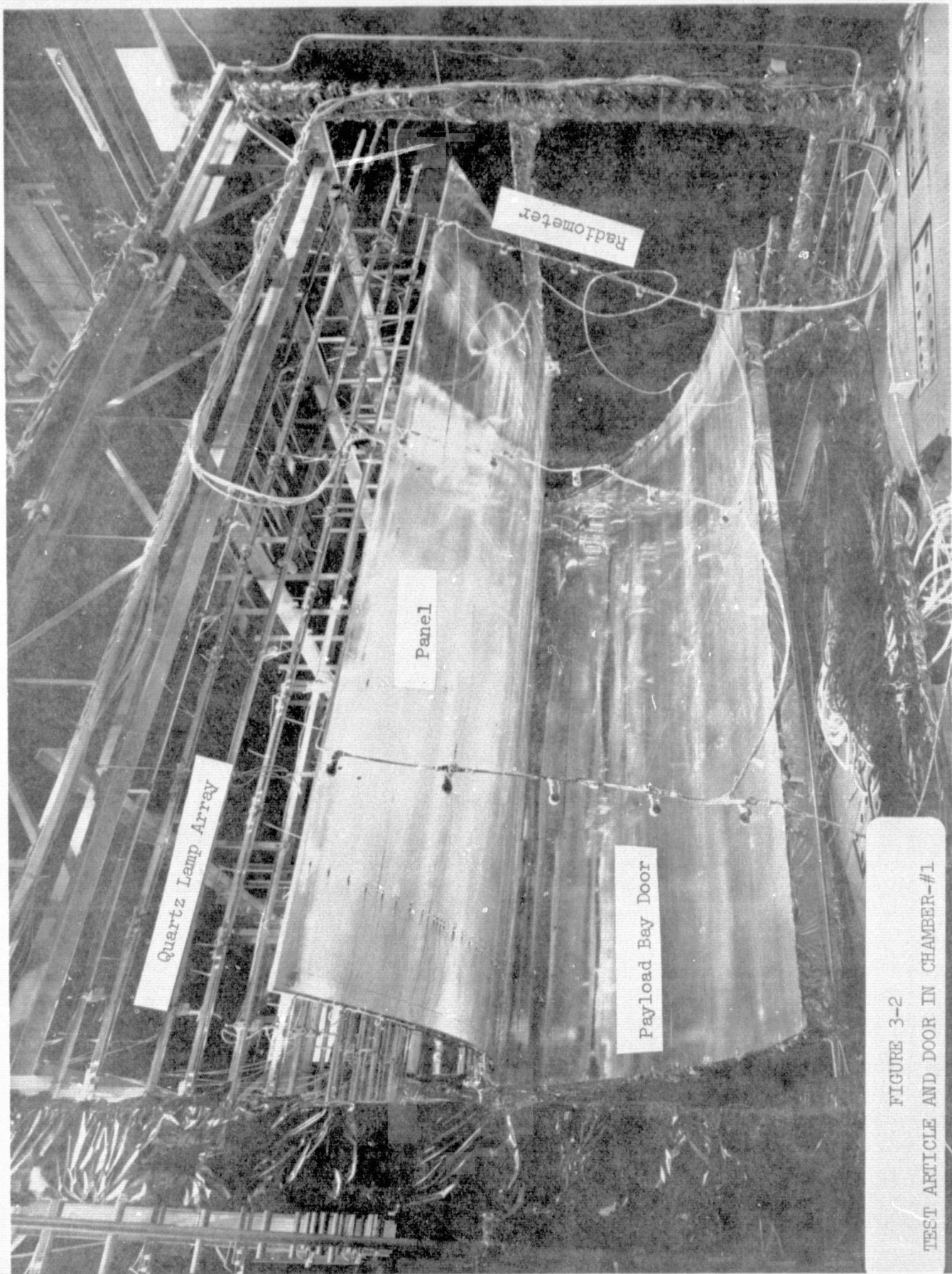


FIGURE 3-2
TEST ARTICLE AND DOOR IN CHAMBER-#1

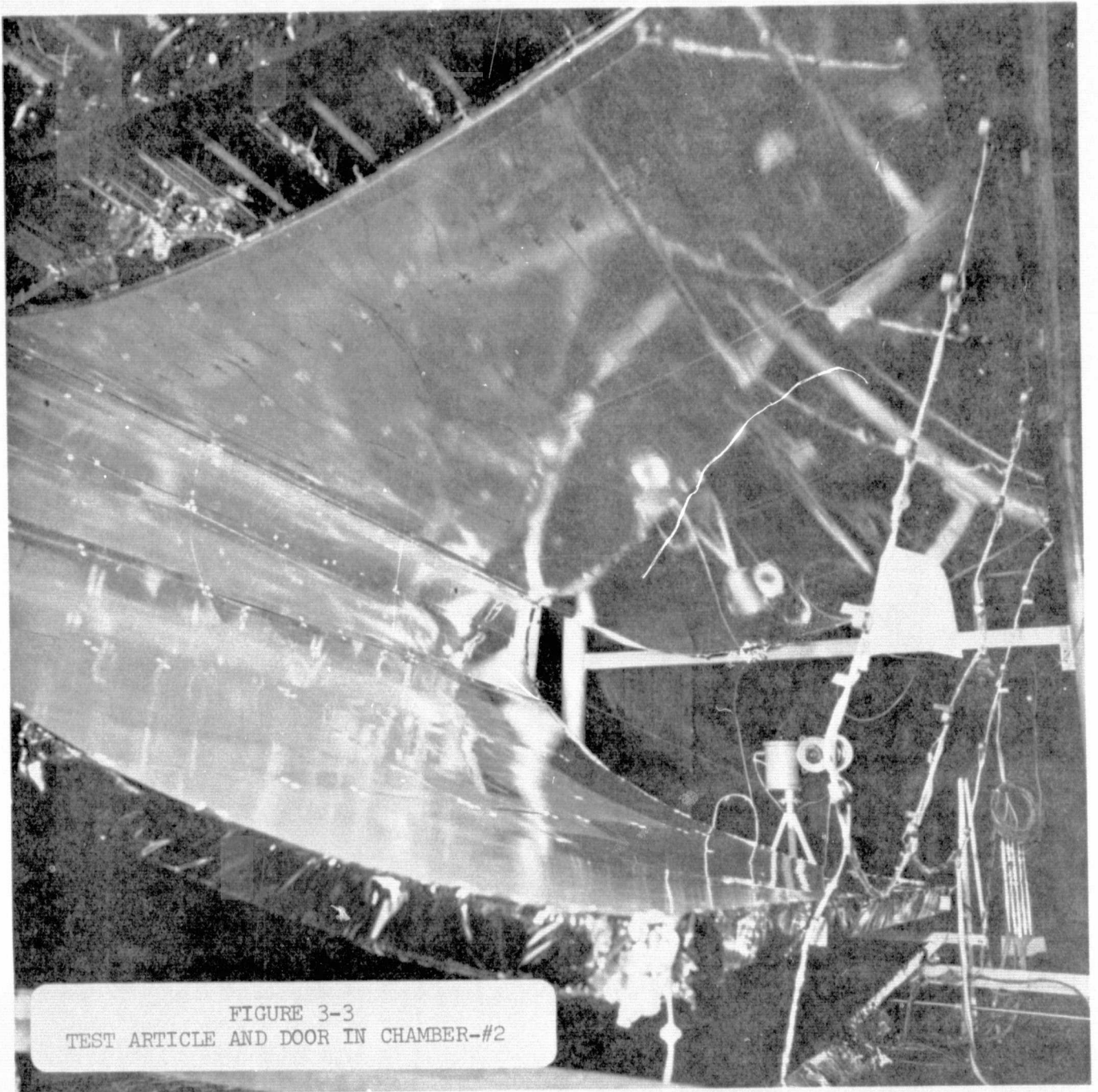


FIGURE 3-3
TEST ARTICLE AND DOOR IN CHAMBER-#2

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FIGURE 3-4
SOLAR MIRROR INSTALLED IN CHAMBER

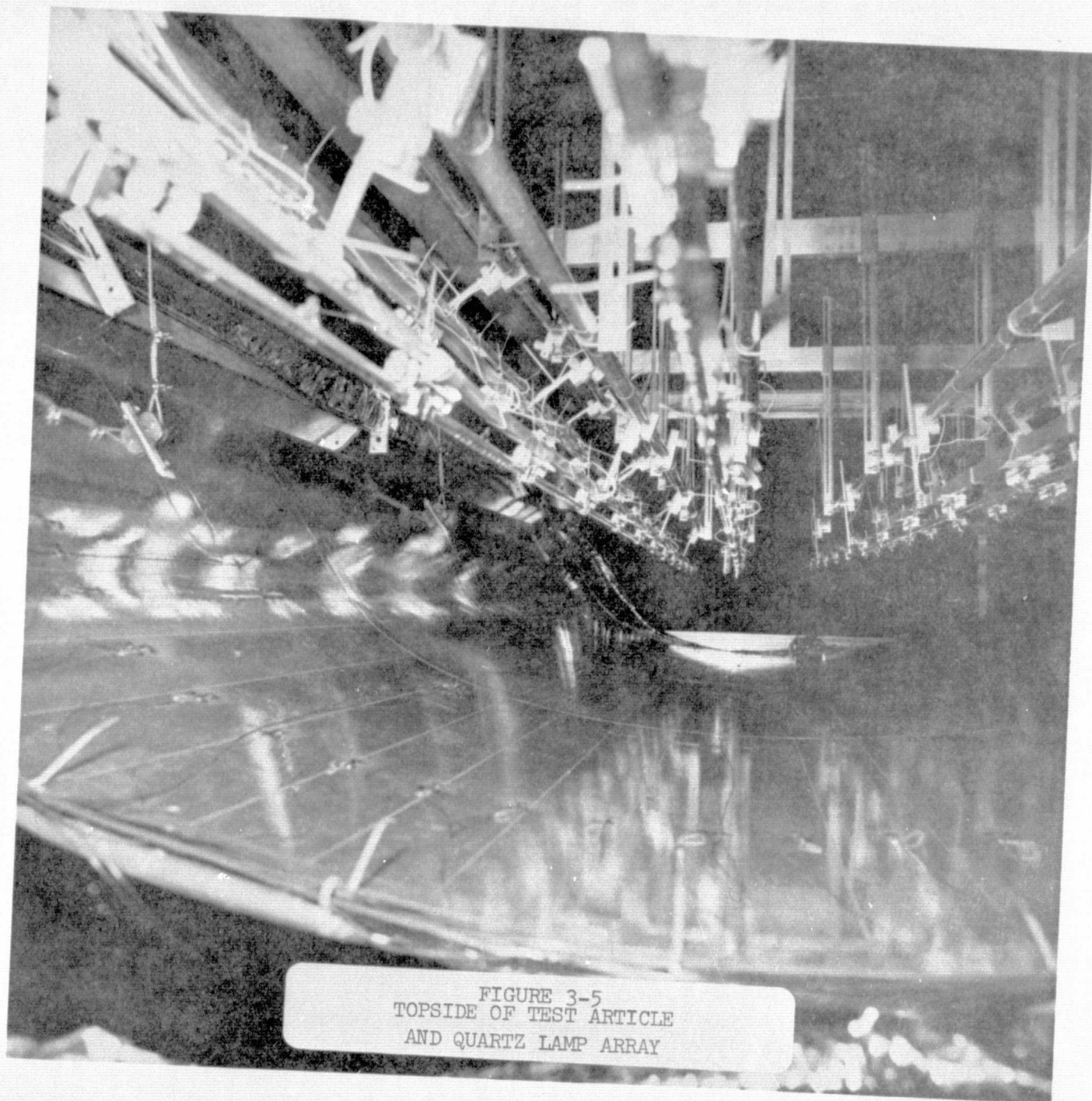


FIGURE 3-5
TOPSIDE OF TEST ARTICLE
AND QUARTZ LAMP ARRAY

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FIGURE 3-6
REPRESENTATIVE PANEL DESIGN

HONEYCOMB PANEL

0.012 in. 2024 T81 ALUM FACE SHEET
5056 H39, 3.1 LB/FT³ ALUM H/C CORE

FORWARD PANEL

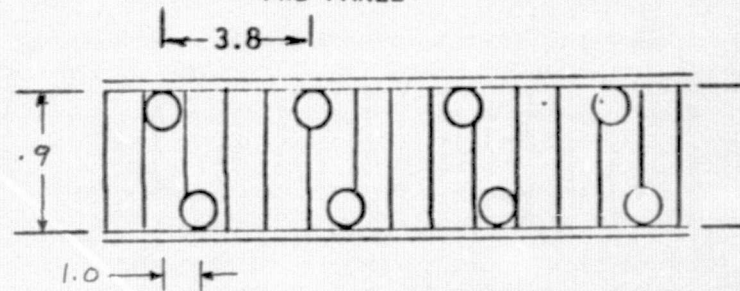
68 TUBES ATTACHED TO ALTERNATE FACE SHEETS
3.8 in. TUBE SPACING, TUBE I.D.=0.1315 in.
0.90in. H/C THICKNESS

TUBES BONDED TO FACE SHEETS

"I" TUBE PANEL



FWD PANEL



3.3 PBD SIMULATOR

The PBD simulator provided thermal radiation characteristics only. No structural simulation of the door is required. The PBD is constructed of 18 separate electrical heater panels, coated with silver teflon, to provide localized heating for the desired environmental profile. The back side of the door is insulated to prevent heat loss and insure that all impressed heat will be "seen" by the panel.

3.4 FLOW CONTROL SYSTEM

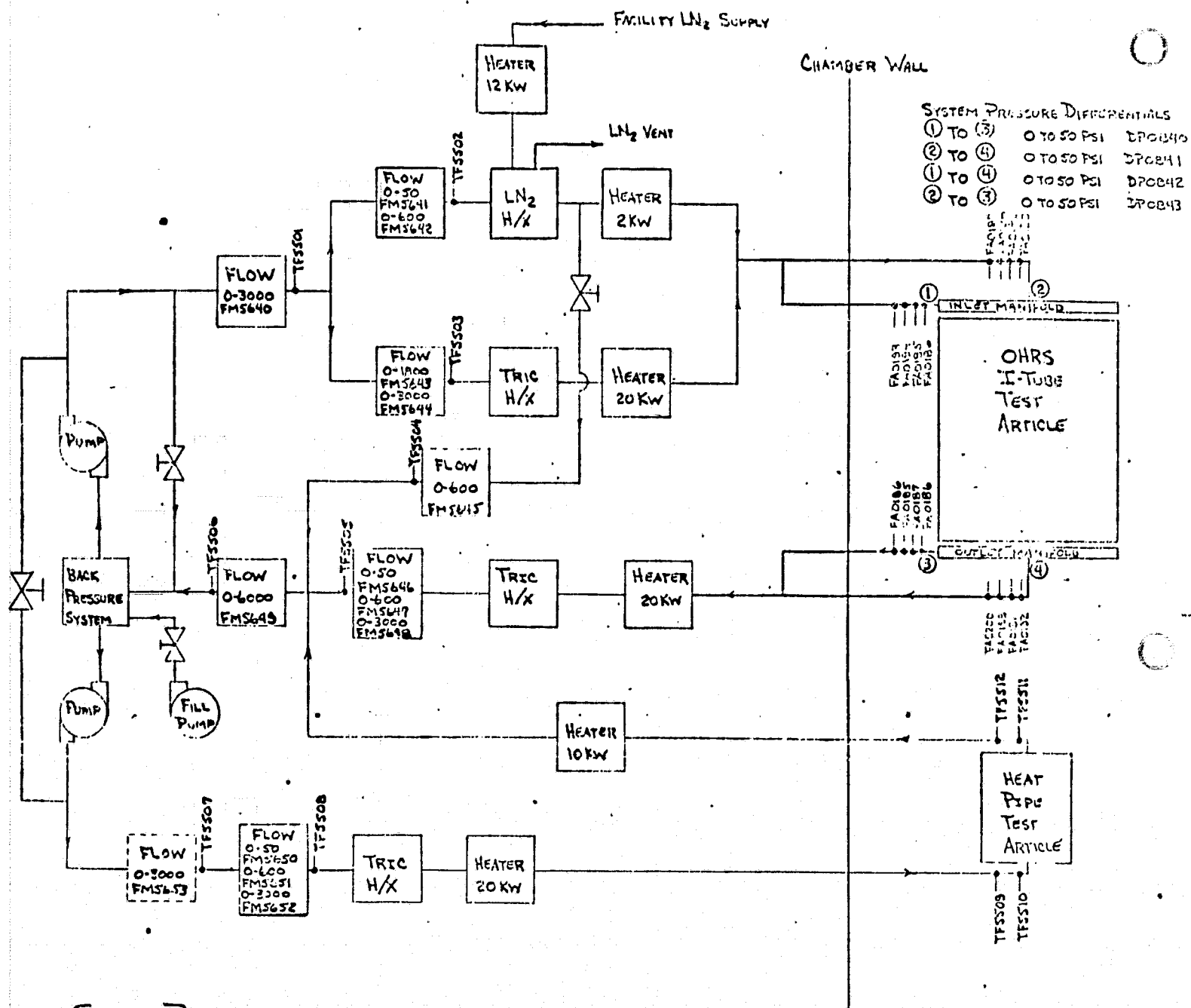
The Freon-21 fluid flow system is a modular component design containing a finned heat exchanger, finned calrod heaters, a liquid nitrogen heat exchanger and a refrigerated trichlorethylene heat exchanger. Flow will be controlled and monitored by a flow meter network with range capability adequate for the test requirements. Figure 3-7 shows a simplified schematic of the freon flow system. The system has the capability of providing conditioning requirements to control radiator inlet temperatures from -180°F to $+140^{\circ}\text{F}$ with a temperature transient of $\pm 60^{\circ}\text{F}$ per hour.

3.5 ENVIRONMENTAL SIMULATION

Simulated solar flux was provided by the SESL Chamber B Xenon lamps. The flux was directed into the test article cavity at a 77° angle by a mirror. IR flux on the radiator panel was simulated by an array of quartz lamps which have been calibrated to provide selected flux levels at pre-determined power settings. In addition, the 18 PBD heater elements provided simulated absorbed flux, as required, on the door.

3.6 INSTRUMENTATION

The test article was instrumented with the thermocouples on the PBD



SYSTEM REQUIREMENTS

INDIVIDUAL POWER CIRCUITS FOR:

220 VOLT

- 2 KW HEATER - QUANTITY 1
- 10 KW HEATER - QUANTITY 1
- 12 KW HEATER - QUANTITY 1
- 20 KW HEATER - QUANTITY 3
- 30 AMP PUMP - QUANTITY 3
- 30 AMP TRIC SYSTEM - QUANTITY 1
- 60 AMP COLO PACK COMPRESSOR - QUANTITY 1

440 VOLT

FLUID:

- FREON 21 - 900 lbs
- FREON 12 - 50 lbs
- TRIETHYLCHLORINE - 55 GALS

INSTRUMENTATION DISPLAY

- 2 ACTIVE ACE CRT'S

FIGURE 3-7
SIMPLIFIED FLOW SCHEMATIC

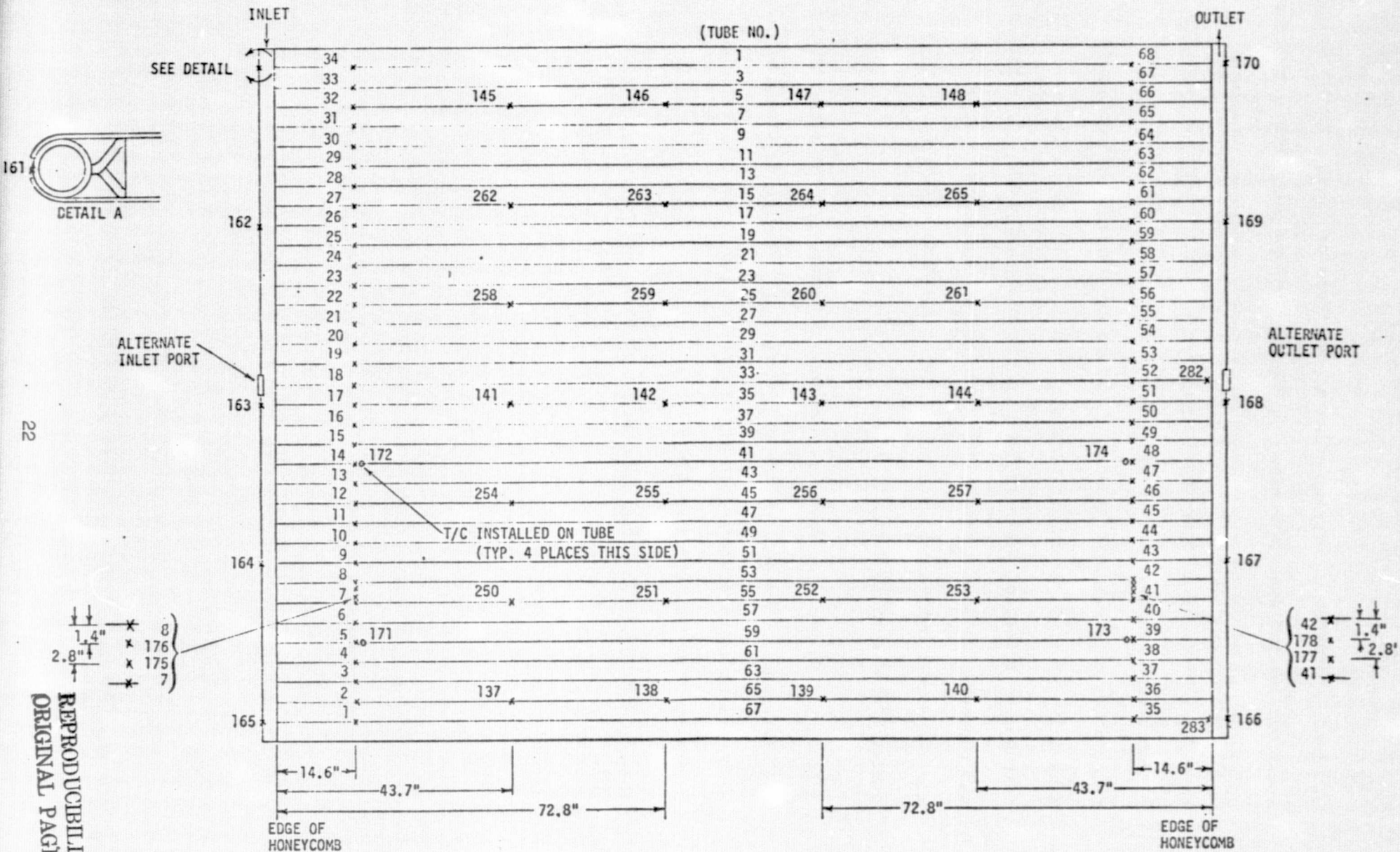
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simulator and on both exterior sides of the radiator panel. Thermocouple locations for the panel are shown in Figures 3-8 and 3-9. PBD thermocouple locations are shown in Figure 3-10. The Freon-21 supply and return lines (see Figure 3-7) were fitted with redundant immersion thermocouples. A temperature reading at each immersion thermocouple location allowed calculation of panel performance. Pressure drop across the radiator, from inlet manifold to outlet manifold, was recorded and displayed. For purposes of this test the transducer on the mid port of the inlet manifold was connected to both transducers on the outlet manifold. Similarly, the transducer on the end port of the inlet manifold was wired to both outlet transducers (see Figure 3-7).

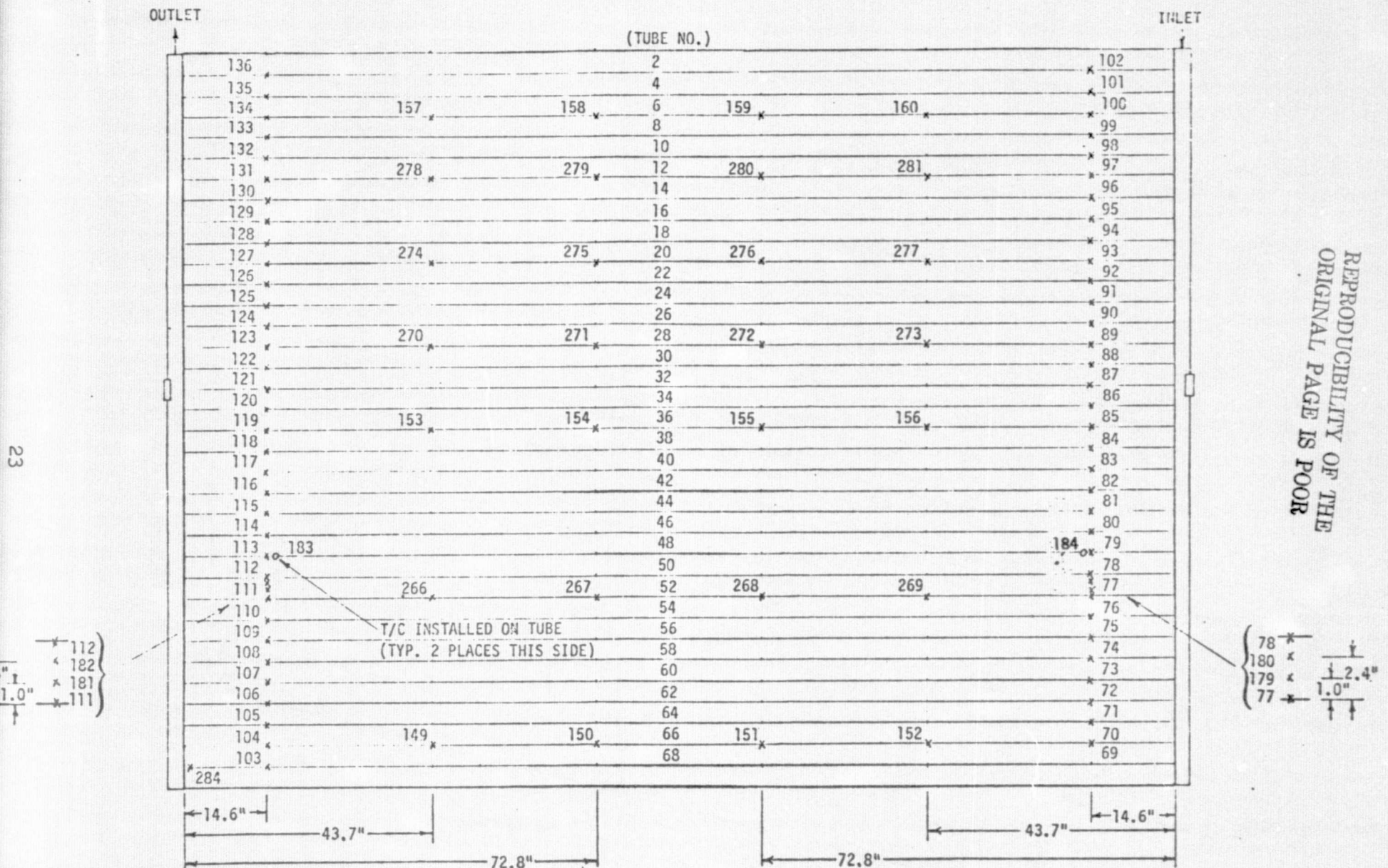
Redundant flow metering devices were used to determine flow rates to the radiator panel. The outlet flow of the radiator was reconditioned to near ambient temperature before measurement to reduce density variation effects on the flow meter readings.

The amp meters on the 12050 power modules, furnished by SESL, were used to determine the power supplied to the PBD heaters. These readings were displayed on the CRT real time.

"TOP RADIATOR PANEL THERMOCOUPLE LOCATIONS
(CONCAVE SURFACE)"



**"BOTTOM" RADIATOR PANEL THERMOCOUPLE LOCATIONS
(CONVEX SURFACE)**



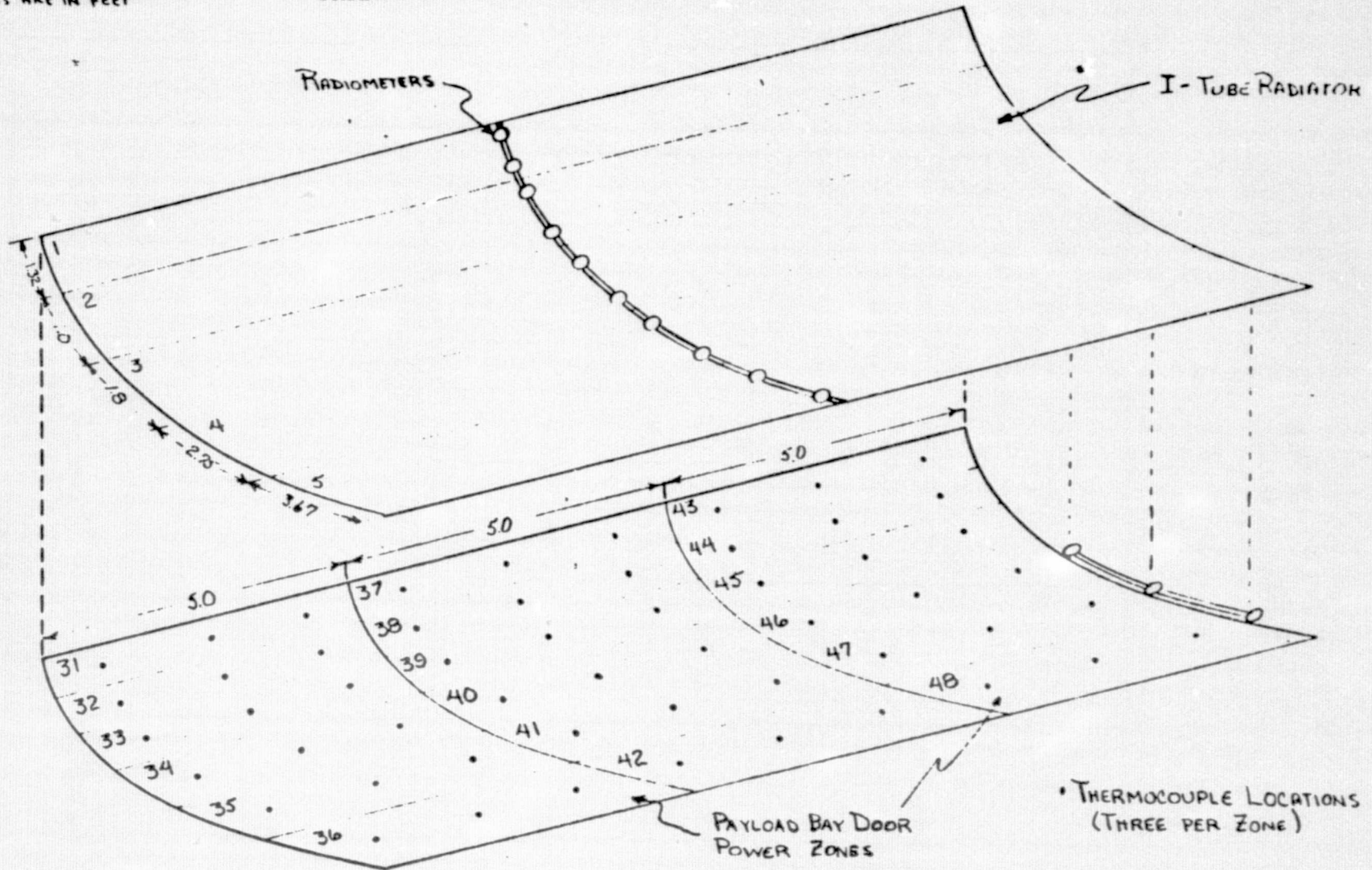
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FIGURE - 3-9

FIGURE 3-10

PAYLOAD BAY DOOR SIMULATOR POWER ZONES

DIMENSIONS ARE IN FEET



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4.0 TEST DESCRIPTION

4.1 SUMMARY

A total of 63 test points were run during the two week test, encompassing approximately 188 hours of thermal vacuum testing. All test objectives were satisfactorily achieved during the test and no retest requirements have been identified.

Tables 4-1 and 4-2 summarize the test points accomplished during the first and second week, respectively.

4.2 TEST NARRATIVE/FACILITY SUMMARY

The testing was accomplished through the joint efforts of Crew Systems Division/Rockwell/Vought as planners and analysts; and Space Environment Test Division/Vought Laboratories with test facility and hardware responsibility. The primary facility functions of high vacuum, deep space simulation, environment simulation, and instrumentation and display were accomplished with very few anomalies.

The SETD personnel were also responsible for designing and constructing all special test equipment, which included quartz lamp array (QLA), quartz lamp support stand, solar mirror support, radiometers, and door actuator. With the possible exception of the radiometers, all special test equipment provided by SETD worked well and met all requirements. The radiometer problems will be discussed in Section 5.2.

Prior to first week chamber door closing, the radiometer and door positions were verified. The two position door was controlled by air actuated

TABLE 4-1
WEEK 1 TEST SUMMARY

* MIRROR IN CHAMBER

TEST PT.	COMPLETION TIME DAY:HR:MIN	DESCRIPTION	T _{IN} OF	T _{OUT} OF	FLOW PPH	T _{PANEL} OF	T _{DOOR} OF	T _{MIRROR} OF	CAVITY ANGLE	ENVIRONMENT SUN	GLA	HTR
101	124:18:38	BACKGROUND	100.8	67.2	2699	76.8	16.6	-152.8	B/L	0	0	0
102	124:21:13	BACKGROUND	60.9	34.3	2699	42.4	-9.4	-162.8	B/L	0	0	0
118	125:02:36	MODEL CORRELATION	60.9	44.2	2726	47.7	63.1	-51.9	B/L	1	0	0
119	125:05:30	↑	100.8	75.8	2699	81.1	80.3	-41.3	↑	1	0	0
120	125:07:30	↓	100.8	70.3	2063	77.4	78.2	-38.6	↓	1	0	0
121	125:10:30	MODEL CORRELATION	61.7	40.9	2689	44.9	60.0	-38.2	B/L	1	0	0
103	125:13:45	QLA CALIBRATION	58.1	51.7	2726	50.3	66.1	-36.6	B/L	1	REF	0
103A	125:16:00	BACKGROUND CHECK	-21.4	-20.9	321	-63.3	-57.7	-93.1	B/L	0	0	0
113	125:20:15	PERFORMANCE MAP	-19.7	-16.2	280	-23.2	-16.4	-42.1	B/L	1	FLT	FLT
127	125:22:00	PERFORMANCE MAP	-19.7	-22.3	280	-25.9	38.6	-45.5	WIDE	1	FLT	FLT
105	126:02:45	MODEL CORRELATION	121.2	96.4	2686	101.5	93.2	-34.6	B/L	1	30	0
106	126:07:00	MODEL CORRELATION	91.1	72.6	2686	75.2	78.6	-35.1	B/L	1	30	0
105A	126:10:30	PERFORMANCE MAP	121.2	96.4	2726	100.4	103.9	-31.9	B/L	1	FLT	FLT
122	126:12:30	β = 95°	120.4	94.9	2726	99.5	920	-35.0	WIDE	1	↑	↑
123	126:14:15	ROLL = 167°	91.1	72.6	2752	750	800	-39.1	WIDE	1	↑	↑
106A	126:17:15	X ON V	91.1	74.2	2726	75.4	90.3	-35.4	B/L	1	↑	↑
107A	126:19:15	↑	60.9	53.4	2752	51.0	79.6	-34.4	B/L	1	↑	↑
124	126:22:00	↑	60.5	49.6	2700	49.8	67.8	-38.0	WIDE	1	↑	↑
125	127:00:00	↑	60.1	47.6	2114	47.3	66.3	-38.3	WIDE	1	↑	↑
108	127:02:15	↑	61.7	50.1	2037	49.4	77.1	-36.6	B/L	1	↑	↑
109	127:05:00	↑	91.1	70.3	2101	730	898	-34.7	B/L	1	↑	↑
126	127:09:15	↑	89.2	67.6	2101	71.4	77.2	-38.0	WIDE	1	↑	↑
110	127:12:00	↑	90.3	64.8	1514	68.7	88.0	-36.7	B/L	1	↑	↑
111	127:14:15	↑	60.9	45.0	1522	46.5	77.6	-32.1	B/L	1	↑	↑
112	127:18:15	↓	60.9	6.4	288	11.7	59.2	-38.4	B/L	1	↓	↓
129	127:21:30	PERFORMANCE MAP	60.5	-3.6	292	6.5	46.5	-43.5	WIDE	1	FLT	FLT
128	127:22:15	RADIOMETER CALIBRATION	60.5	-3.6	292	6.5	46.5	-43.5	B/L	1	0	0
101A	128:00:45	REPEAT 101	100.8	66.4	2752	76.4	12.9	-102.0	B/L	0	0	0
101B	128:02:00	L-TUBE COMPARISON	102.3	64.8	2500	751	16.7	-112.7	B/L	0	0	0
130	128:05:45	COLD SOAK FOR	72.7	-16.2	1002	-0.2	-43.0	-153.2	B/L	0	0	0
132	128:10:00	RADIOMETER	-95.4	-112.7	557	-98.8	-117.8	-175.8	B/L	0	0	0
133	128:14:00	DATA	-164.9	-174.0	623	-169.9	-153.6	-182.3	B/L	0	0	0

TABLE 4-2
WEEK 2 TEST SUMMARY

TEST PT	COMPLETION TIME DAY: HR: MIN	DESCRIPTION	T _{IN} OF	T _{OUT} OF	FLOW PPH	T _{PANEL} OF	T _{DOOR} OF	CAVITY ANGLE	ENVIRONMENT QLA HTR
201	138:11:15	BACKGROUND	100.1	65.2	2759	76.6	5.7	B/L	0 0
202	138:15:45	BACKGROUND	60.1	32.3	2699	41.1	-22.1	B/L	0 0
203	138:17:15	EXCHANGE	60.5	35.5	2745	43.4	39.7	B/L	0 40°
203A	138:18:30	FACTOR	80.4	51.3	2739	60.0	39.7		0 40°
204	138:19:30	DETERMINATION	100.4	66.8	2759	76.6	39.8		0 40°
215	139:00:15	REPEAT DALLAS TP 7	60.1	-50.0	306	-41.6	-82.9		0 0
214	139:10:15	TEST POINTS TP 18	-166.3	-179.7	338	-174.3	-178.3		0 0
211	139:16:00	LOW LOAD TESTING	-172.9	-189.2	237	-182.5	-189.8		0 0
208	139:21:30	BASELINE CAVITY	-135.1	-176.1	172	-159.9	-182.4		0 0
210	140:00:15		-176.0	-196.2	174	-188.1	-192.0		0 0
209	140:03:30		-181.9	-202.4	139	-194.3	-198.8		0 0
212	140:06:15		-132.2	-160.6	313	-148.8	-183.7		0 0
207	140:10:00		-69.4	-112.1	385	-96.9	-147.9		0 0
213	140:14:00	LOW LOAD TESTING	-119.6	-146.0	314	-130.7	-164.2	3/L	0 0
404	140:15:45	LOW LOAD TESTING	-117.7	-141.6	385	-129.7	-169.8	WIDE	0 0
408	140:22:00		-174.7	-198.6	172	-188.3	-198.1	WIDE	0 0
409	141:00:15	WIDE CAVITY	-178.8	-203.8	142	-194.2	-232.1	WIDE	0 0
301	141:15:15	L-TUBE COMPARISON	110.0	80.0	2507	88.7	42.4	3/L	40 ON
301A	141:17:00		109.2	77.7	2532	87.0	27.4	WIDE	
302A	141:18:45		82.3	57.2	2513	64.5	14.3	WIDE	
302	141:20:30		82.3	58.8	2513	65.0	27.2	B/L	40
303	141:23:15		88.4	74.6	2500	76.7	62.2	B/L	80
303A	142:01:00		88.4	71.8	2513	75.1	49.0	WIDE	
304A	142:02:45		102.3	83.1	2526	86.8	54.3	WIDE	
304	142:04:15	L-TUBE COMPARISON	102.6	85.8	2540	85.5	70.6	B/L	80 ON
308	142:08:15	SOLAR SIMULATION	119.4	101.6	2726	104.1	119.1	5/L	VAR ON
308A	142:12:15		120.0	94.8	2719	100.1	103.5	5/L	VAR ON
308B	142:13:45	SOLAR SIMULATION	120.0	96.4	2726	101.1	-	5/L	VAR ON
402	142:15:30	EXCHANGE	106.8	66.0	2726	75.9	40.3	WIDE	0 40°
402A	142:16:30	FACTOR	80.4	50.1	2712	58.9	39.5	WIDE	0 40°
401	142:17:15	DETERMINATION	60.9	35.1	2712	42.6	39.7	WIDE	0 40°
306	142:20:00	L-TUBE COMPARISON	100.2	89.5	2513	90.0	103.1	3/L	VAR ON

cylinders with cables whose length determined the door position. The "nominal" cavity opening was set such that the distance from the outboard edge of the door was 78 ± 1 inches from the outboard edge of the radiator panel. This represented a deployment angle of 35.5 degrees.

The wide cavity setting was restricted the first week by the width of the solar beam. The widest door opening that provided full sun in the cavity resulted in an edge-to-edge length of 96" or approximately a 46 degree deployment angle.

Before chamber closeout, it was necessary to attach bundles of gold kapton at the top of the solar mirror to diffuse a portion of the solar beam that was imaging on the top side of the radiator. The necessary environment on the top of the panel was provided by the quartz lamps, and the irregular solar spillover was not desirable.

With the previously mentioned final arrangements completed, the chamber pumpdown was initiated at 0620 on May 3. Chamber pressure was reduced to test condition ($<10^{-5}$ torr) and test point 101 was initiated. Mirror background test points were accomplished and the solar simulators were activated at approximately 2100 on May 3.

During the mirror background points, the top-mounted radiometers were observed to indicate a larger-than-anticipated flux reading, causing a modification in the timeline to allow study of the problem before the quartz lamps were turned on. Thus, the four model correlation test points were accomplished with the sun on, quartz lamps off, with various flow rates and inlet temperatures. These points (118-121) were completed at 1030 on May 4.

It was next determined to run a QLA calibration point to verify the lamp settings. This test point (103) was accomplished, followed by a test point (103A) intended to identify the radiometer readings under cold conditions. The purpose of this test point was to ensure that the radiometers did indeed read close to zero for cold conditions. Thus, the sun and QLA were turned off at 1345 allowing the panel to soak to a cold condition.

Following this, low load, high environment test points were accomplished for both nominal (T.P. 113) and wide (T.P. 127) cavity angles, demonstrating stability under these conditions. Following this, a uniform environment (80 Btu/hr ft²) mapping sequence was accomplished, completed at 0700 of May 5.

The original test profile was resumed with a mapping sequence tending to duplicate a $\beta = 90^\circ$, roll = 167° flight condition. This sequence was modified to include alternating nominal and wide cavity cases, to conserve test time. These test points were completed at 2130 on May 6.

Data was gathered as the solar modules were turned off (T.P. 128) and a test point was run to check repeatability of thermocouple readings. Following this, a test point (101B) was accomplished to exactly duplicate an L-tube flow and inlet condition. A final sequence was added to gather radiometer data during an extended cold soak (T.P. 130, 132, 133) and the first week of testing was terminated at 1400 on May 8.

The major modifications made between the first and second week of testing were as follows:

- . mirror removed, solar modules blanketed
- . thermocouples added to QLA support structure
- . cavity radiometer relocated to top side of panel
- . panel tilted such that outboard edge was 7.5" below inboard edge
- . flow bench modifications made to allow lower inlet temperatures
- . door cables adjusted to give cavity heights of 78" (nominal) and 102" (wide)

The second week of testing was initiated on May 17. The first series of test points (201, 202) were completed at 1545, providing a check on the contribution due to the mirror in the chamber the first week.

Three test points (203, 203A, 204) were then accomplished to gain data for determination of radiation exchange factors between panel and door. These points utilized the door heaters to maintain isothermal conditions on the door as panel conditions were changed.

Following this, two test points (215, 214) were run to compare performance with that observed in Vought/Dallas testing of the same panel without the PBD. These points were completed 1015 on May 18, and the low load stability sequence was begun.

The purpose of the low load stability sequence was to identify the lowest system load that could be rejected without freezing the forward panel. This sequence involved the real time correlation of a radiator thermal system model (T.P. 211) and subsequent prediction of low load flow rates and inlet temperatures. This was accomplished under conditions representing both

forward and mid-forward panel configurations (Section 5.2.3). These points were completed at 1400 on May 19. A similar, although shorter, sequence followed with the door dropped to the 50° position.

At the beginning of the next sequence, an electrical malfunction of the QLA required an unscheduled repressurization of the chamber. This delay of approximately 9 hours required a review of the priorities of the remaining test points, and the eventual deletion of two low priority points.

Following chamber pumpdown a sequence was run to compare to L-tube test results (see Sect. 5.4.3) with uniform fluxes of 40 and 80 Btu/hr ft² applied to the top of the panel via the QLA. Both nominal and wide door positions were tested alternately. The sequence included 8 test points (301-304, 301A-304A) and was completed at 0445 on May 21.

The next test sequence was run in an attempt to increase confidence in the use of the QLA for total flux simulation, including solar. Multi-panel qualification testing will be of necessity conducted in chambers without solar capability. Three test points (308, 308A, 308B) to accomplish this objective were completed at 1345.

Another exchange factor determination sequence was accomplished (test points 402, 402A, 401), followed by a skewed flux comparison with August 1975 L-tube testing, and the second week testing was terminated at 2000 on May 22.

The following sections of this report describe the test data and major results from the test program.

5.0 TEST RESULTS

5.1 TEST DATA INDEX

The data gathered during the two weeks of testing is in four basic formats, described as follows:

- a. Compressed data, stored on the compressed data tapes (CDT) which were continuously updated throughout the testing.
- b. Computer plots of specific data from CDT.
- c. Computer printouts ("SCOOPS") of all data; generated every 15 minutes throughout the test and more often for specific purposes.
- d. Continuous real time hand plots of key data, prepared by the test team. These plots included Freon-21 flow and temperature, environment parameters, heat rejected, and various structure temperatures. In addition, special purpose temperature maps and profiles were prepared after each test point.

Categories a and c above are available by contacting Mr. W. E. Ellis at NASA-JSC, telephone (713) 483-4941. Category b is included in Appendix A of this report. Category d is included in Appendix B of this report. Appendices A and B are separately-bound volumes of this report. Table 5-1 summarizes the data presented in each of these two appendices.

TABLE 5-1
TEST DATA INDEX

Data Presented in
Appendix

Description

A
(VOLUME II)

Continuous Computer Plots of:

- (a) Payload Bay Door Average Temps
 - (b) Mirror Average Temps
 - (c) Radiometer Raw Data and Averages
 - (d) Calculated Heat Rejection
 - (e) Freon 21 Inlet/Outlet Temps
 - (f) Isolation Panel Temps
 - (g) Freon 21 Conditioning System Flows
 - (h) Structure Temps(second week only)
-

B
(VOLUME III)

Continuous Hand Plots of:

- (a) Average Door Temp
 - (b) Average Mirror Temp
 - (c) Average Panel Temp
 - (d) Average Isolation Panel Temp
 - (e) Average Radiometer Readings
 - (f) Freon 21 Inlet/Outlet Temps
 - (g) Calculated Heat Rejection
 - (h) Freon 21 Flowrate to Panel
-

End-of-Test-Point Plots of:

- (a) Panel Temperature Profile
 - (b) Specific Tube Temperature Profiles
 - (c) Tube Inlet/Outlet Temp Profiles
 - (d) Payload Bay Door Zone Averages
-

The total heat absorbed by the test panel from various heat sources in the chamber is a key parameter in the description of radiator performance. Ideally, the test panel is placed in a controlled environment which represents deep space (0 Btu/hr/ft^2 absorbed) at the low end, and various skewed environment distributions representative of typical orbiter situations. Since the silver-Teflon coating properties are a highly sensitive function of the wavelength of the incident radiation, the spectral distribution of the environment is as important a variable as is its intensity.

Numerous compromises must be made in the selection of test environments, and the exact value of the environment was a source of continuing uncertainty throughout the test. This uncertainty was due to the limited number of radiometers available for measurement, the questionable accuracy of the radiometers, and the unknown effect of the background radiation due to the considerable amount of support structure needed to accommodate the test article, the quartz lamp array, and the heat pipe test article.

The purpose of this section is to resolve as many of these uncertainties as possible and reconcile the probable environment with panel performance and model correlation information.

5.2.1

Radiometer Location/Calibration

A total of 26 Hy-cal water-cooled radiometers were used during the testing. During the first week, 15 of these were located in the plane of the cavity, 8 were located on the top side of the panel, and 3 were positioned on the door edge. After the first week, 10 of the 15 cavity

radiometers were repositioned to locations on top of the panel and above the panel. Table 5-2 and Figure 5-1 describe and display the radiometers.

Three different radiometer faces were used: (1) Standard black face with absorptivity approximately equal to 1 for all wavelengths, (2) quartz windows which were intended to reflect IR wavelengths and measure only solar-wavelength environment, and (3) silver-Teflon coated faces for the measurement of absorbed flux on the panel independent of spectral distribution. Of these categories, data from the quartz-windowed radiometers was generally unusable due to incorrect calibration. In addition, quartz windows were inadvertently placed on three radiometers during the first week which caused loss of this data.

The calibration of the radiometers involved ascertaining the sensitivity factor which related the millivolt output of each thermopile to a displayed reading in Btu/hr/ft^2 . A heat balance on the radiometer face reveals that the actual incident flux is the sum of two terms, an absorbed term which provides a potential across the thermopile, and a reemitted term.

$$Q = -MS + \sigma T^4$$

This equation shows that the device is expected to respond linearly to the absorbed term (sensitivity S times millivolt reading M). The purpose of the water cooling is to maintain the base of the device at a known temperature such that the reemitted term (σT^4) is held approximately constant.

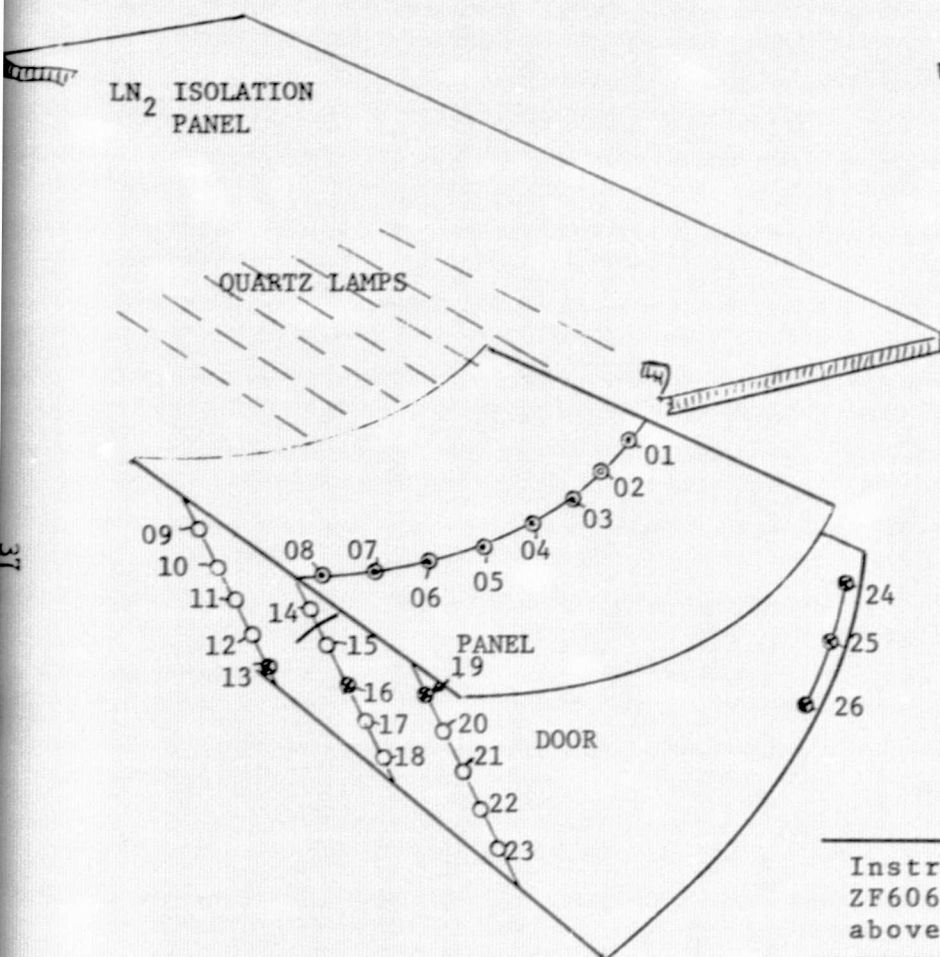
TABLE 5-2 DESCRIPTION OF RADIOMETERS

WEEK	NUMBER OF RADIOMETERS	INSTRUMENT NUMBERS	WINDOW OR COATING	LOCATION/VIEW	Fig 5-1 Symbol
1	12	ZF6069-72, 74, 75, 77, 78, 80-83	black window	plane of cavity, normal to cavity	○
	3	ZF6073, 76, 79	quartz* window	plane of cavity, normal to solar beam	⊙
	8	ZF6061 thru ZF6068	silver-Teflon coated	topside of panel, looking at QLA	⊙
	3	ZF6084, 85, 86	quartz** window	edge of payload bay door, looking upward at bottom of panel	⊙
2	5	ZF6074 thru ZF6078	black window	plane of cavity, normal to cavity	○
	8	ZF6061 thru ZF6068	silver Teflon coated	topside of panel, looking at QLA, as in week 1	⊙
	5	ZF6069 thru ZF6073	black window	topside of panel, looking at QLA	□
	3	ZF6079 ZF6080 ZF6081	black window	on LN ₂ isolation panel, looking downward at test fixture	□
	2	ZF6082 ZF6083	black window	on QLA structure, looking up at LN ₂ isolation panel	□
	3	ZF6084 ZF6085 ZF6086	black window	edge of PBD, looking upward at bottom of panel	⊙

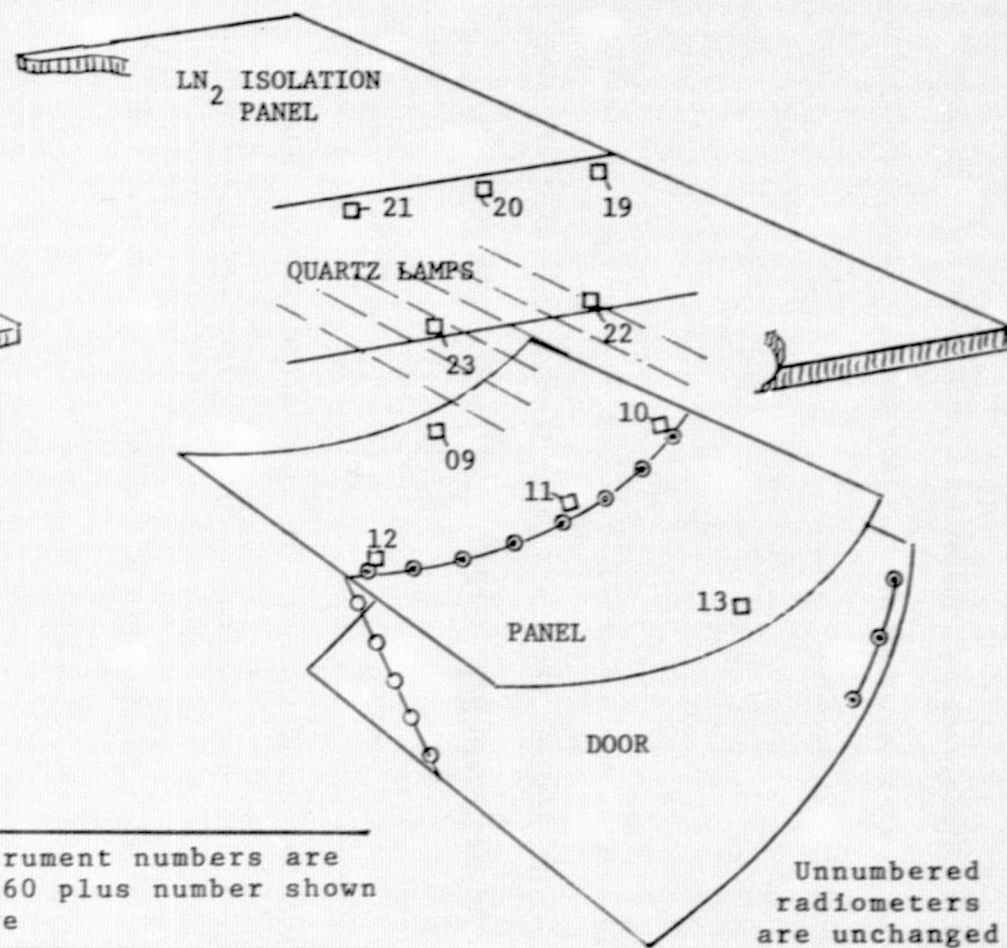
*Calibrated incorrectly

**Quartz windows inadvertently left on

FIGURE 5-1
LOCATION OF RADIOMETERS



WEEK 1



WEEK 2

Instrument numbers are
ZF6060 plus number shown
above

Unnumbered
radiometers
are unchanged
from first week

In calibration tests, each radiometer is placed in a small chamber and subjected to an incident flux near zero ($Q=Q_0$). The above equation is then solved for S yielding

$$S = \frac{-Q_0 + \sigma T^4}{M_0}$$

With a radiometer maintained at 70°F , and an environment kept small by the use of LN_2 through the black walls of the small chamber, the term Q_0 can be neglected with respect to the T term, yielding

$$S = \sigma T^4 / M_0$$

The sensitivities thus determined are used in the computer program which converts millivolt readings to flux readings during the test.

With a silver-Teflon coating on the face of the radiometer, the sensitivity values are determined by the equation

$$S = \epsilon \sigma T^4 / M_0$$

The ultimate equation relating millivolt reading to flux for silver-Teflon coated radiometers is thus

$$Q = -SM + \epsilon \sigma T^4 = \frac{-\epsilon \sigma T_0^4}{M_0} M + \epsilon \sigma T^4$$

The silver-Teflon radiometers were calibrated without consideration of the emissivity of the Teflon, resulting in test data readings which were a constant factor of ϵ too high. Thus, all test data was multiplied by .76 post-test to reduce the data to its proper value.

5.2.2 Radiometer Corrections

In addition to the calibration error mentioned in the previous section, three other corrections were found necessary to reduce the radiometer readings to usable data. These corrections will be discussed in the following paragraphs.

The ultimate use of flux readings is to determine the total absorbed heat on the panel, a value that can be used in the overall heat balance for the panel. Since there is not perfect uniformity between the environment seen at the centerline of the panel (where the majority of the radiometers were located) and the ends of the panel, a correction was applied to the flux readings before a total absorbed heat is calculated. The background flux due to the structure, for example, would be expected to be less at the ends of the panel, where the view of the structure is less than at the center.

A TRASYS model was created to measure this effect by comparing the form factors between elements at the center of the panel and elements at the end of the panel, with the LN_2 panel.

In particular, the form factor between the LN_2 panel and an element in the center of the panel is .64, while the same factor between the LN_2 panel an entire end-to-end strip is .58. Assuming that all flux originates at the LN_2 panel (i.e., through reflections from the panel) at an effective temperature, T_o , the respective fluxes are

$$\text{Flux at center} = q_c = \frac{\epsilon_L \sigma T_o^4 (\bar{T}_A)_{L-C}}{A_c}$$

$$\text{Flux on strip} = q_s = \frac{\epsilon_L \sigma T_o^4 (\bar{T}_A)_{L-S}}{A_s}$$

The ratio of these fluxes is then

$$\frac{q_c}{q_s} = \frac{\bar{T}_{L-C}/A_c}{\bar{T}_{L-S}/A_s} = \frac{.866/1.35}{11.85/20.29} = 1.099$$

Since we are measuring q_c , and seek to calculate q_s , the average over the entire strip, the equation for correction of the center radiometer readings is thus

$$q_s = \frac{q_c}{1.099} = .91 q_c$$

Another correction to the radiometer reading was made to compensate for an apparent discrepancy between the millivolt reading used in calibration (measured directly with a small voltmeter), and the millivolt signal as processed during the test by the on-line computers. The nature of this discrepancy can be seen by reference to Figure 5-2 in which raw radiometer data is plotted against a measure of panel heat rejection, given by σT^4 . The basic linearity of this functional relationship is obviously demonstrated by these curves, leading to the conclusion that the environment seen by the top-side of the panel was basically determined by reflections from the LN_2 panel and structure.

When all radiometers are plotted as in the format of Figure 5-2, it becomes obvious that the vertical intercepts are more-or-less randomly distributed about zero, as likely to be negative as positive. Table 5-3 displays the observed vertical intercepts for the important radiometers,

FIGURE 5-2
RAW RADIOMETER DATA FOR
VARIOUS PANEL EMISSIONS

FLUX ~ BTU/HR/FT² X 17.4

FLUX ~ BTU/HR/FT²

RADIOMETER 6067

6062

6064

6061

$\sigma T_{\text{PANEL}}^4 \sim \text{BTU/HR/FT}^2$

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and the shift applied to the data to adjust the curve such that its intercept becomes the analytically-estimated value of absorbed flux due to emission from surrounding structure. Those values are 3 BTU/hr/ft² for topside radiometers, and 2 BTU/hr/ft² for cavity radiometers, calculated using assumptions as to the amount of aluminum structure, and temperature observations from week 2.

TABLE 5-3

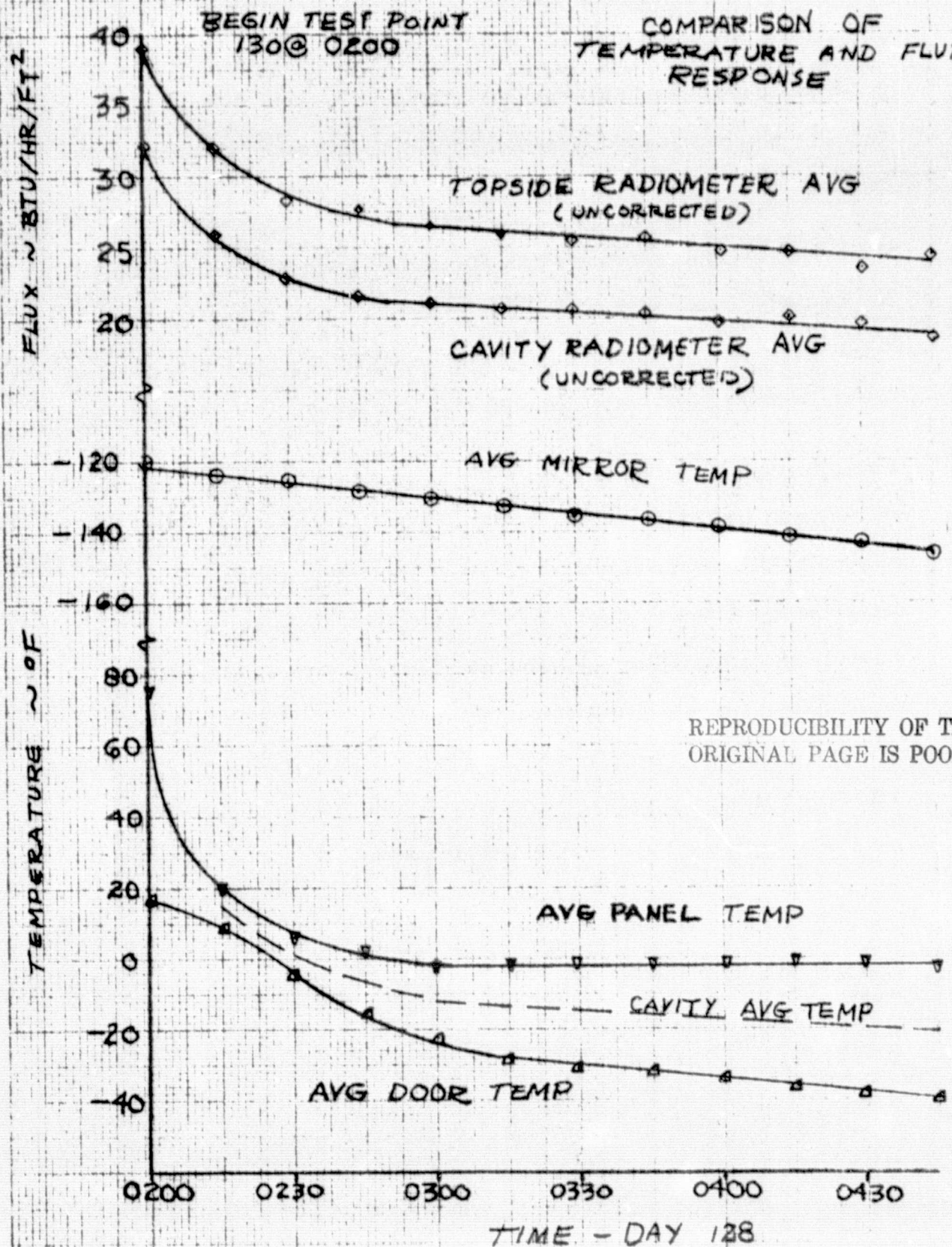
RADIOMETER CORRECTIONS

	<u>Radiometer Number</u>	<u>Intercept</u>	<u>Required Shift</u>
TOP OF PANEL	ZF6061	+ 3	0
	ZF6062	+ 1	+ 2
	ZF6063	+ 7	- 4
	ZF6064	- 7	+10
	ZF6065	- 2	+ 5
	ZF6066	- 6	+ 9
	ZF6067	- 2	+ 5
	ZF6068	+ 4	- 1
PLANE OF CAVITY	ZF6074	+ 3	- 1
	ZF6075	- 1	+ 3
	ZF6076	- 1	+ 3
	ZF6077	+ 5	- 3
	ZF6078	- 7	- 5
ON ISOLATION PANEL	ZF6079	-32	+35
	ZF6080	-13	+16
	ZF6081	+24	-21
ABOVE QLA	ZF6082	- 6	+ 9
	ZF6083	- 2	+ 5

Figure 5-3 shows test data plotted during a cool-down test point which supports the conclusion that the measured environment was much more strongly a function of reflected flux than true "background" radiation being emitted from surrounding structure. As can be seen from the temperature profiles, the radiometer response matches the panel temperature

FIGURE 5-3

COMPARISON OF
TEMPERATURE AND FLUX
RESPONSE



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response for the majority of its variation. Similar data was observed during the second week when thermocouples were installed on the structure above the panel. The conclusion to be drawn is that the emitted flux was a small part of the overall environmental heating experienced by the test article, and cannot be used to explain abnormally high radiometer readings.

The third correction involves the flux readings on each radiometer due to their direct view of the panel itself. While this flux is "real" it is not considered a part of the external environment, but rather is energy leaving the system which is immediately reabsorbed.

A TRASYS model produced exchange factors from each element of the panel to the remainder of the panel, and was used to calculate this direct component, which must be subtracted from the actual reading to determine net external flux. The direct component is obviously directly proportional to the panel average temperature, and was recalculated for each panel condition.

Tables 5-4 and 5-5 summarize the corrected environment data for each test point in week 1 and week 2, respectively.

TABLE 5-4

WEEK 1 CORRECTED RADIOMETER DATA
(BTU/HR/FT²)

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TEST POINT	T ₄ T _{PAN}	PANEL TOP SIDE (SILVER TEFLON)										T ₄ T _{CAV}	T ₄ T _{MIN}	PLANE OF CAVITY (BLACK)																	GAGE CAND	SOLAR	WIDE CAVITY DOOR	HEATERS
		G061	G062	G063	G064	G065	G066	G067	G068	AVG	G069			G070	G071	G072	G074	G075	G077	G078	G080	G081	G082	G083	AVG									
101	142	20	21	23	26	23	25	16	19	22	113	15	38	32	33	29	34	40	34	28	33	36	16	12	33									
101A	142	17	21	20	26	24	21	16	17	20	114	28	38	34	36	31	34	42	38	31	35	37	32	15	38									
101B	142	17	21	20	26	24	21	16	18	20	112	23	38	33	34	29	34	42	35	29	33	37	28	14	38									
102	109	15	17	16	20	21	20	14	17	17	88	13	31	23	26	22	27	32	26	23	26	28	25	8	31									
103	116	53	61	60	65	60	58	53	56	58	116	55	410	422	403	340	450	347	383	369	426	366	382	306	384									
105	170	28	36	46	53	54	55	53	54	47	166	56	469	467	432	339	442	349	381	363	432	375	396	304	396									
103A	169	65	61	47	46	36	34	26	27	43	166	58	459	459	425	334	444	349	379	364	429	375	408	303	394									
105	141	32	43	48	55	55	56	54	50	49	142	56	459	456	426	336	456	353	374	361	424	368	379	303	391									
106A	141	70	64	50	44	42	39	27	27	45	149	56	465	463	423	343	439	342	382	371	420	361	385	245	391									
107A	117	74	66	50	49	42	40	28	28	47	131	55	449	447	410	342	436	336	374	364	419	353	355	292	383									
108	168	65	62	47	47	40	34	24	27	43	128	55	451	447	405	344	434	335	364	350	419	353	390	284	379									
109	138	71	60	47	45	42	39	27	28	45	146	56	460	455	422	355	437	342	371	360	427	363	361	293	389									
110	134	70	62	52	51	37	35	26	30	45	143	55	453	448	382	344	432	338	377	366	423	358	388	286	383									
111	113	73	65	50	48	41	36	27	27	46	127	57	448	446	377	344	428	332	364	360	418	354	375	289	378									
112	85	40	35	28	30	23	21	15	18	26	103	54	440	435	367	337	418	319	356	355	410	342	360	278	368									
113	62	46	39	31	29	26	19	16	16	28	85	50	453	447	417	330	430	324	362	354	409	345	391	299	380									
112	114	18	21	20	23	21	22	18	17	20	120	47	436	440	410	333	456	344	393	387	426	337	389	281	386									
118	147	21	26	22	25	24	25	20	20	23	146	53	R	430	R	324	452	342	376	372	431	358	395	287	377									
120	143	16	25	24	27	24	27	19	23	24	143	54	428	432	411	330	447	346	372	355	419	365	398	304	384									
121	111	14	20	18	24	21	22	16	19	19	118	54	416	421	396	320	426	330	355	343	407	359	394	297	372									
122	168	65	61	48	47	41	34	26	27	44	163	56	446	476	429	334	450	357	382	375	431	340	399	305	398									
123	140	70	60	46	44	42	39	27	28	45	143	54	467	499	449	339	446	352	382	376	424	383	402	305	402									
124	116	74	66	51	50	43	40	27	29	47	124	54	450	482	434	339	446	350	374	374	424	373	378	294	393									
125	114	75	66	51	50	42	37	25	28	47	122	54	462	497	440	350	424	338	371	367	424	373	377	294	393									
126	137	68	61	51	46	36	34	25	30	44	139	54	425	457	412	345	436	350	369	361	428	377	385	291	387									
127	61	45	38	30	29	25	19	15	16	27	81	50	448	478	433	328	439	338	367	360	409	360	381	290	386									
129	81	36	35	24	26	22	21	16	17	25	96	51	433	462	384	335	430	343	355	359	408	364	374	284	378									
130	77	12	14	12	16	17	16	10	12	14	52	15	25	18	20	18	23	24	20	19	18	23	10	4	23									
132	29	8	7	4	10	10	12	7	9	9	26	11	15	6	8	6	12	11	8	10	9	11	13	0	12									
133	12	7	5	3	7	7	9	5	6	6	13	10	13	4	4	2	7	6	5	8	6	10	5	-2	6									

TABLE 5-5

WEEK 2 CORRECTED
RADIOMETER DATA
(BTU/HR/FT²)

TEST POINT	T _{FM} ⁴	PANEL TOP SIDE (SILVER TEFLON)									T _{CAV} ⁴	PLANE OF CAVITY (BLACK)						QUARTZ LAMP	WIDE CAVITY	DOOR HEATERS
		G061	G062	G063	G064	G065	G066	G067	G068	AVG		G074	G075	G076	G077	G078	AVG			
201	142	12	19	19	26	21	23	16	19	19	108	8	9	9	11	19	11			
202	103	12	15	16	20	18	18	13	16	16	83	6	8	7	8	15	9			
203	109	11	16	16	20	17	18	13	14	16	109	7	8	8	9	15	9			
203A	125	11	17	18	22	19	19	14	17	17	116	7	9	8	9	17	9			
204	142	12	19	19	24	19	21	15	18	18	124	9	10	8	9	17	11			
207	29	5	5	5	7	6	5	5	6	5	22	3	3	3	3	5	3			
208	14	4	4	3	4	4	5	4	4	4	12	2	3	3	3	3	3			
209	9	2	4	3	3	3	4	3	4	3	8	2	2	2	2	2	2			
210	9	3	3	3	4	4	5	4	4	4	9	2	3	2	2	2	2			
211	10	3	3	3	4	5	5	3	4	4	9	4	2	2	2	4	3			
212	16	3	4	3	4	6	6	4	4	4	13	4	2	3	3	3	3			
213	20	2	3	4	6	5	6	4	5	4	16	2	4	2	3	4	3			
214	11	4	4	4	6	5	5	3	5	5	11	4	3	3	3	4	3			
215	52	5	10	10	11	9	10	7	9	9	42	6	6	5	5	8	6			
301	155	48	60	58	64	60	59	56	58	58	131	10	12	13	13	22	14			
301A	153	48	59	59	62	60	60	56	59	58	122	10	12	11	12	25	14			
302	130	46	58	57	61	59	59	54	57	56	112	10	11	11	11	20	13			
302A	130	47	58	57	61	57	58	55	56	56	107	10	11	10	11	23	13			
303	142	82	97	95	100	96	93	90	95	94	135	12	13	13	12	23	15			
303A	140	82	77	95	100	98	93	90	95	94	122	11	13	13	12	26	15			
304	155	85	101	98	102	97	96	92	96	96	144	12	13	12	12	24	15			
304A	153	83	94	95	100	98	95	91	97	95	136	11	13	13	13	28	16			
306	157	87	111	105	111	105	120	101	89	106		10	13	12	13	24	13			
308	173	109	113	86	81	80	79	73	75	87	183	10	12	11	13	24	14			
308A	168	95	84	62	53	45	47	45	49	60	171	11	12	11	11	23	14			
308B	169	96	85	62	54	45	46	44	50	60		10	12	11	12	23	14			
401	109	14	17	17	20	18	14	14	16	17	109	7	9	9	9	18	10			
402	141	14	19	20	24	19	21	16	17	19	123	9	9	9	9	19	11			
402A	124	17	21	22	27	23	23	17	19	21	116	9	9	9	10	22	8			
404	20	9	3	3	6	6	4	4	3	4	16	3	4	2	2	4	3			
406	9	2	2	3	4	3	3	3	4	3	9	3	2	1	2	3	2			
407	8	3	3	3	4	4	4	3	4	3	8	3	3	2	2	2	2			

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5.2.3 Chamber Reflections

Figure 5-4 displays the results of plotting corrected radiometer readings against a measure of total cavity emission. For this purpose, cavity emission is expressed by σT_{CAV}^4 where $T_{\text{CAV}} = (T_{\text{PANEL}} + T_{\text{DOOR}})/2$. The basic linearity of the relationship supports the conclusion that the flux incident on the cavity membrane is primarily due to reflections from the chamber wall. A perfectly absorbing chamber would cause radiometer readings at the membrane to respond independent of the cavity temperature.

This data indicates that at high load conditions, approximately 9-11 BTU/Hr/ft² is reflected into the cavity. For a cavity opening area of 170 ft² (including ends), this translates to a flux load on the cavity of 1530 - 1870 BTU/Hr. Approximately 75% of this load is ultimately absorbed by the panel through direct and reflected paths, and through absorption and reemission by the door.

Figure 5-4 also demonstrates that by turning on the quartz lamps an additional 4 BTU/Hr/ft² is incident on the cavity.

5.2.4 Structure/LN₂ Panel Reflections

Figure 5-5 displays average readings for the eight radiometers mounted on the top-side of the radiator panel. As with the cavity radiometer data, the flux is approximately a linear function of panel emission (measured by σT_p^4), indicating an environment controlled primarily by reflections from the QLA structure and LN₂ panel.

Several second week test points (401, 402, 402A) were conducted immediately after the QLA had been on for an extended period. The

FIGURE 5-4
CHAMBER BACKGROUND AND REFLECTED FLUX

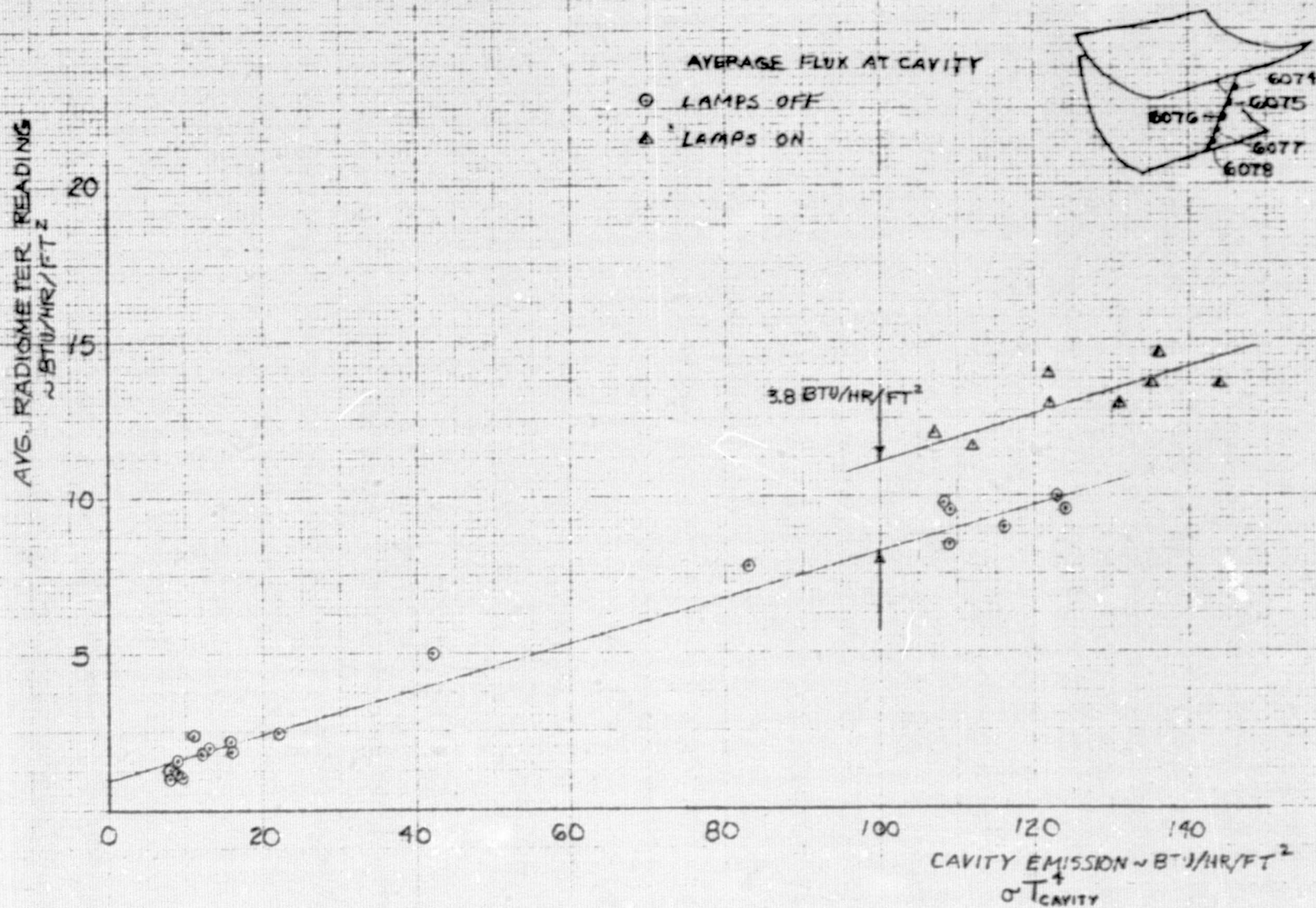
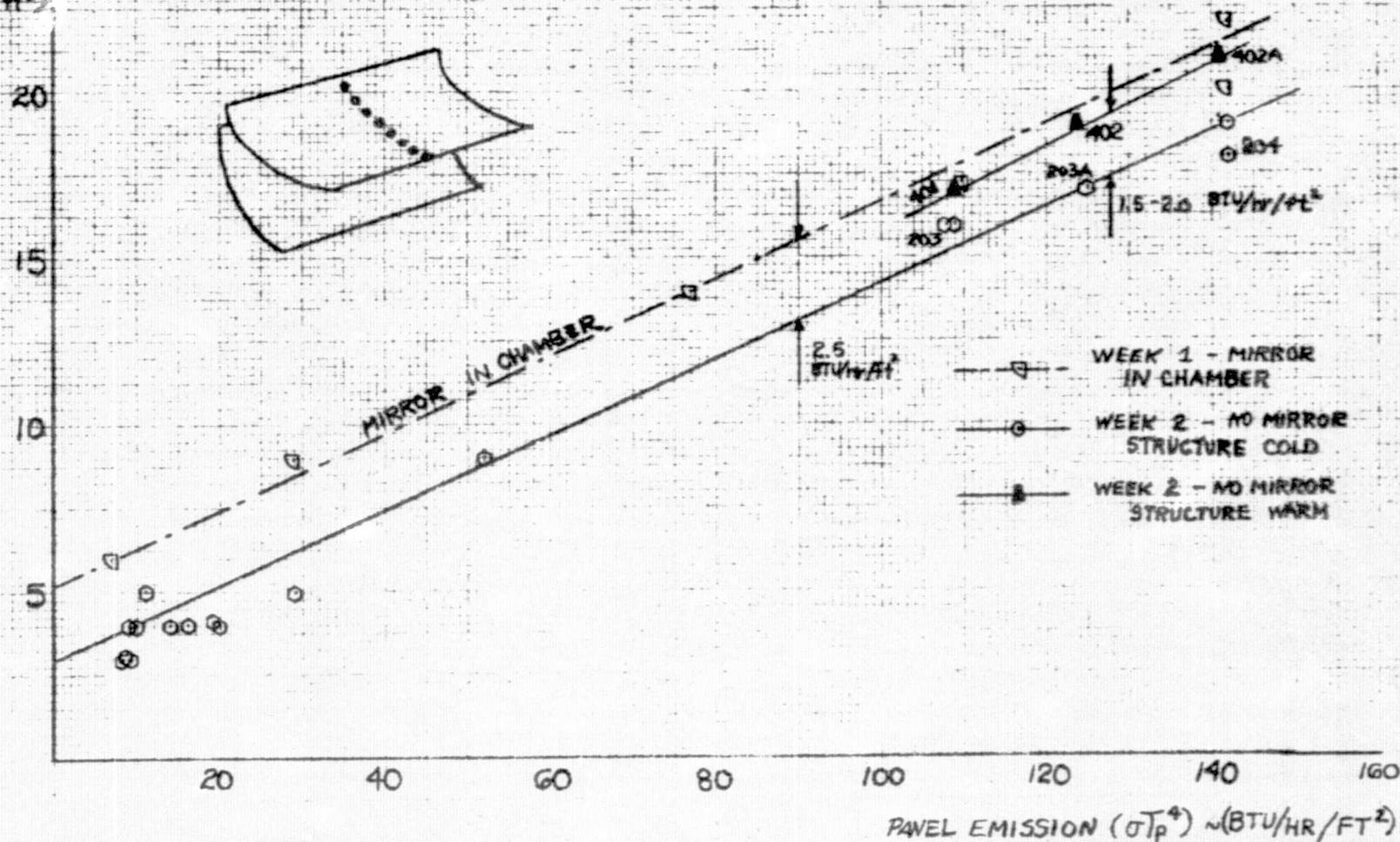


FIGURE B-5
RADIATOR TOPSIDE AVERAGE FLUX

AVERAGE
RADIOMETER
READING
(BTU/HR/FT²)

• SUN OFF
• QUARTZ LAMPS OFF



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effect of the warm structure can be seen to be approximately a 1.5 - 2.0 BTU/Hr/ft² increase in recorded flux. Reference to the following table and Figure 5-5 demonstrates the small effect that the structure temperature has on environment.

STRUCTURE TEMPERATURE	WARM STRUCTURE			COLD STRUCTURE		
	401	402	402A	203	203A	204
ST0811	-19	-9	6	-75	-77	-75
ST0812	-50	-43	-34	-90	-90	-91
ST0813	-13	-3	14	-71	-71	-71
ST0814	1	11	27	-72	-71	-66
ST0815	-1	11	26	-25	-25	-21
ST0816	-26	-12	2	-80	-79	-83

The top side environment measured for the high heat rejection test points is in the range of 17-20 BTU/hr/ft². This data has already been corrected such that it represents average absorbed flux over the entire panel (see Section 5.2.2). Thus for the 160 ft² panel the total absorbed heat is estimated to be 2750-3240 BTU/hr, significantly higher than had been expected.

Figure 5-5 also demonstrates that the mirror in the chamber during the first week caused an increase in top-side flux of 2.5 BTU/Hr/ft² or a total additional top-side load of 400 BTU/Hr.

5.2.5 Quartz Lamp Environment

Figure 5-6 displays an estimation of the flux due to turning on the quartz lamp system above the panel. Note that this estimation is not necessary, since the radiometer array always measures total absorbed flux, which is the only important quantity for radiator analysis. This

AVG RADIOMETER
READING (CORRECTED)
BTU/HR/FT²

FIGURE 5-6
CORRECTED RADIOMETER
READINGS

PANEL TOPSIDE
WEEK TWO

LAMPS ON
NOMINAL 80 BTU/HR/FT²

LAMPS ON
NOMINAL 180 BTU/HR/FT²

LAMPS OFF

74 BTU/HR/FT²

56 BTU/HR/FT²

DUE TO
REFLECTIONS

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0 20 40 60 80 100 120 140 160

PANEL EMISSION $\propto T^4$

section is an attempt to verify the various approximations made to radiometer data by checking the corrected data against anticipated results.

Figure 5-6 concludes that the nominal setting of 40 BTU/Hr/ft² actually produced an average absorbed flux of 36 BTU/Hr/ft², while the nominal 80 setting resulting in an additional flux of 74. These results are deemed entirely consistent with the degree of accuracy with which the original lamp settings were calibrated, and with the accuracy of the radiometers.

The incremental flux due to the lamps is due to direct and multiple bounces between the panel and the lamp structure. The lamp flux causes the panel to heat up and thus contribute more to the reflected environment, but this effect is accounted for in Figure 5-6 by plotting vs. panel emission σT_p^4 and measuring the incremental distance between the plots after fitting parallel lines to the lamps-on data points. Since a wide range of panel temperatures was not tested with the lamps set to predetermined flux levels, a large amount of interpolation is necessary to interpret the data.

5.2.6

Mirror Effect

The mirror used during the first week to reflect simulated sunlight into the cavity also caused an additional IR load due to reflections and emissions. This effect can be approximated by comparing radiometer readings from the first and second week. Only sun-off test points can be used for this purpose since the high solar flux overwhelms the IR effect when the solar simulators are on.

Figure 5-7 compares radiometer averages from week 1 data with the linear response noted in week 2 and discussed in section 5.2.3. The upper curve approximates the flux due to reflections and was used in the energy balance of section 5.2.8.

As expected, the presence of the mirror causes a larger amount of emitted flux to be reflected back into the cavity. The approximate amount of this flux is 35 BTU/hr/ft^2 at high load conditions vs. only 9 BTU/hr/ft^2 in the absence of the mirror. For the 96 ft^2 cavity opening, this flux represents approximately 3360 BTU/Hr at high loads, of which roughly 75% is ultimately absorbed by the panel. The low load flux load on the cavity due to the mirrors is approximately 860 BTU/Hr .

Since the cavity radiometers measure total absorbed flux when the suns are on, the approximate value of IR flux must be subtracted from the total radiometer reading to determine solar load. The next section discusses this in greater detail.

FIG. 5-7

ESTIMATION OF FLUX DUE
TO SOLAR MIRROR

CAVITY
AVERAGE
FLUX
BTU/hr/ft²

40

30

20

10

0

20

40

60

80

100

120

140

160

CAVITY EMISSION $\sigma T_{\text{cav}}^4 \sim \text{BTU/hr/ft}^2$

WITH MIRROR

WITHOUT MIRROR (FROM FIGURE 5-4)

54

Solar Load

The solar absorptance of a 38° cavity with a 77° sun has been previously studied during the cavity assessment test program (Reference 3). It was determined that 4680 BTU/hr was absorbed by the radiator panel (both directly, and through reflection from the door). The present test differs from the earlier test in the following ways: (1) there is a mirror which attenuates the solar beam in the current test, (2) the current test article has a 35.5° deployment vs. 38° previously, and (3) the door is the same piece of equipment but is one year older and thus is expected to have altered absorptance and specularity.

The effect of mirror is evaluated by comparing the radiometer data at the cavity with radiometers above the mirror. The average radiometer reading at the cavity was on the order of 380 BTU/Hr/ft^2 and from Figure 5-7, approximately 35 BTU/Hr/ft^2 of this was due to mirror IR (see section 5.2.6). Thus 345 BTU/Hr/ft^2 is attributable to solar flux. The fact that the radiometers were tilted 26° with respect to the solar beam indicates that the solar flux was

$$Q_s = \frac{345}{\cos(26^\circ)} = 384 \text{ BTU/Hr/ft}^2$$

Assuming 1 sun (442 BTU/hr/ft^2) above the mirror results in an attenuation of 13% by the mirror, a value consistent with expectations. Analyses have indicated that the 35° cavity has a greater trapping effect on solar energy incident on the cavity (Reference 4). The effective cavity solar absorptivity is 22% greater for the 35° cavity than for the 38° cavity for a 77° sun angle. Since a flux of 442 BTU/hr/ft^2 was shown to produce a total panel absorption of 4680 BTU/hr for a 38° cavity with an incident area of 105 ft^2 (Ref. 3), it is expected that a flux of 384 BTU/hr/ft^2 will produce an absorption of 4535 BTU/hr for the 35° cavity with a 96 ft^2 area. This is calculated as follows.

$$Q_s = 4680 \times \frac{384}{442} \times \frac{96}{105} \times 1.22 = 4535 \text{ BTU/hr}$$

Thus the previously determined absorption was ratioed by the area difference, the absorption difference and by the incident flux difference between the two tests. The resultant solar absorbed load is a gross approximation which can be tested in an energy balance.

5.2.8

Verification of Environment Data

An energy balance can be written for the radiator panel and tested for its ability to predict total heat rejection as measured experimentally by freon temperature and flowrate observations. The testing of the assumptions and corrections on environment data can be done sequentially to isolate questionable data. In particular, the simplest test points to check are those with (1) no solar, (2) no mirrors, and (3) quartz lamp off. By contrast, test points with solar and quartz lamp environment involve the use of considerable assumptions on environment.

The energy balance for the panel can be written as follows:

$$\begin{aligned} Q_{\text{REJ}} &= \text{Exchange with chamber} + \text{exchange with door} \\ &\quad - \text{absorbed load from mirror (week 1)} - \text{absorbed} \\ &\quad \text{load from solar lamps (week 1)} - \text{absorbed load from} \\ &\quad \text{quartz lamps and reflections} \end{aligned}$$

$$\begin{aligned} Q_{\text{REJ}} &= \left[(FA)_{P-W} \sigma (T_P^4 - T_W^4) + (FA)_{P-D} \sigma (T_P^4 - T_D^4) \right. \\ &\quad \left. - Q_M - Q_S - \epsilon_P A_P - q_c (FA)_{P-C} \right] \quad (\text{Eq. 1}) \end{aligned}$$

Where subscripts P, W, D, M, S, C refer to panel, wall, door, mirror, solar, and cavity respectively.

- δ Is heat flux as measured by radiometers, BTU/Hr/ft²
- A_p Is area of one side of panel, ft²
- T Is average temperature, °R
- Q Is total load, BTU/Hr
- η Is fin efficiency
- (FA) Is exchange factor, ft²

The terms δ_p and δ_c are the corrected flux values on the panel-mounted and cavity-mounted radiometers, respectively.

The terms Q_M and Q_S are the absorbed heat terms due to the mirror and solar lamps, respectively.

For second week test points, $Q_M = Q_S = 0$, and since the contribution from the walls will be measured by the radiometers, T_W must be set = 0 to avoid double consideration of that component. Equation 1 thus reduces to

$$Q_{REJ} = (FA)_{P-W} \eta \sigma T_P^4 + (FA)_{P-D} \eta (T_P^4 - T_D^4) \quad (\text{Eq 2})$$

$$- \delta_P A_P - \delta_C \eta (FA)_{P-C}$$

The relevant exchange factors are as follows:

	<u>35.5° Cavity *</u>	<u>50° Cavity</u>
Panel-To-Wall	184 Ft. ²	190 Ft. ²
Panel-To-Door	54	48
Panel-To-Cavity	33	42

Tables 5-6 and 5-7 present the results of the heat balance (Equation 2) applied to data gathered during week 1 and 2, respectively. Figures 5-8 and 5-8A show plots of the calculated heat rejection versus that which was observed ($wC_p\Delta T$). The week one results for the 35° cavity test points (Figure 5-8) indicate a good agreement, generally confirming assumptions made and corrections to radiometer readings. Figure 5-8A reveals that the calculated heat rejection is higher than the observed when the quartz lamp array is on (shaded symbols on Figure 5-8A). The other test conditions, including when the door heaters only were on, again confirm the assumptions and corrections made to the radiometer readings.

TABLE 5-6

HEAT BALANCE RESULTS - WEEK 1

FIN EFF	.96	
AREA TOPSIDE	160.28	
SCRIPT FA PANEL-WALL		184
SCRIPT FA PANEL-DOOR		54
SCRIPT FA PANEL-MEMB		33
MIRROR IN CHAMBER		

*****HEAT BALANCE TERMS*****						HEAT REJECTION	
TEST PT	TO WALLS	TO DOOR	FROM GLA	FROM CAV	FROM SUN	CALCULATED	OBSERVED
101	25138	2793	3385	1045	0	21725	22545
101A	25064	2681	3077	1203	0	23465	23530
101B	24822	2696	3077	1203	0	23238	23286
102	19288	1997	2615	982	0	17688	17533
130	13532	1285	2154	728	0	11935	11696
132	5153	293	1384	380	0	3682	3516
103	20530	- 781	8324	1215	4535	5048	4479
105	30095	510	7231	1573	4535	17239	16764
105A	29860	- 221	6616	1622	4535	16839	17004
106	24840	- 187	7539	1376	4535	11178	12343
106A	24878	- 847	6924	1431	4535	11114	11445
107	20642	-1474	7231	1274	4535	6101	5063
108	20385	-1411	6616	1257	4535	6539	5792
109	24434	- 947	6924	1418	4535	10583	10843
110	23655	-1070	6924	1389	4535	8379	9558
111	19926	-1573	7077	1247	4535	5467	5922
112	14988	-2058	4000	1041	4535	3327	3770
118	20115	- 749	3077	1192	4535	10535	11149
119	25954	44	3538	1411	4535	16487	16810
120	25251	- 44	3692	1384	4535	15569	15647
121	19675	- 722	2923	1169	4535	10249	10625

TABLE 5-7

HEAT BALANCE RESULTS - WEEK 2

FIN EFF .96
 AREA TOPSIDE 160.28
 SCRIPT FA PANEL-WALL 184
 SCRIPT FA PANEL-DOOR 54
 SCRIPT FA PANEL-MEMB 33
 NO MIRROR IN CHAMBER

*****HEAT BALANCE TERMS***** HEAT REJECTION

TEST PT	TO WALLS	TO DOOR	FROM GLA	FROM CAV	FROM SUN	CALCULATED	OBSERVED
201	25101	3187	2923	348	0	25017	23935
202	19089	2335	2461	285	0	18678	18311
203	19442	165	2461	285	0	16861	16768
203	22136	956	2615	285	0	20192	19646
204	25101	1822	2769	348	0	23806	23043
207	5262	701	769	95	0	5099	4336
208	2455	193	615	95	0	1938	1644
209	1509	29	461	63	0	1014	668
210	1654	26	615	63	0	1002	823
211	1795	53	615	95	0	1138	904
212	2839	315	615	95	0	2444	2067
213	3559	364	615	95	0	3213	2410
214	2016	32	769	95	0	1184	1059
215	9277	926	1384	190	0	8629	7889
301	27104	2940	8324	443	0	20677	19929
302	22913	2227	8616	411	0	16113	15583
303	25120	765	14463	475	0	10947	8576
304	27065	1726	14617	506	0	13668	12117
306	27704	-803	16310	411	0	10180	7106
308	30656	-995	13386	443	0	15832	12227
308	29796	-214	9232	443	0	19907	17232
308	30009	-152	9232	443	0	20182	16187

FIN EFF .96
 AREA TOPSIDE 160.28
 SCRIPT FA PANEL-WALL 190
 SCRIPT FA PANEL-DOOR 48
 SCRIPT FA PANEL-MEMB 42
 MIRROR IN CHAMBER

*****HEAT BALANCE TERMS***** HEAT REJECTION

TEST PT	TO WALLS	TO DOOR	FROM GLA	FROM CAV	FROM SUN	CALCULATED	OBSERVED
301A	27988	2613	8324	564	0	21113	20418
302A	23750	1550	8616	524	0	16160	16147
303A	25631	1173	14463	604	0	11737	10361
304A	27683	733	14771	604	0	13041	10654
401A	19949	115	2615	403	0	17046	17089
402A	25785	1565	2923	443	0	23984	23573
402A	22665	809	3231	322	0	19921	20243

FIGURE 5-8
CALCULATED VS OBSERVED
HEAT REJECTION
WEEK ONE - WITH MIRROR

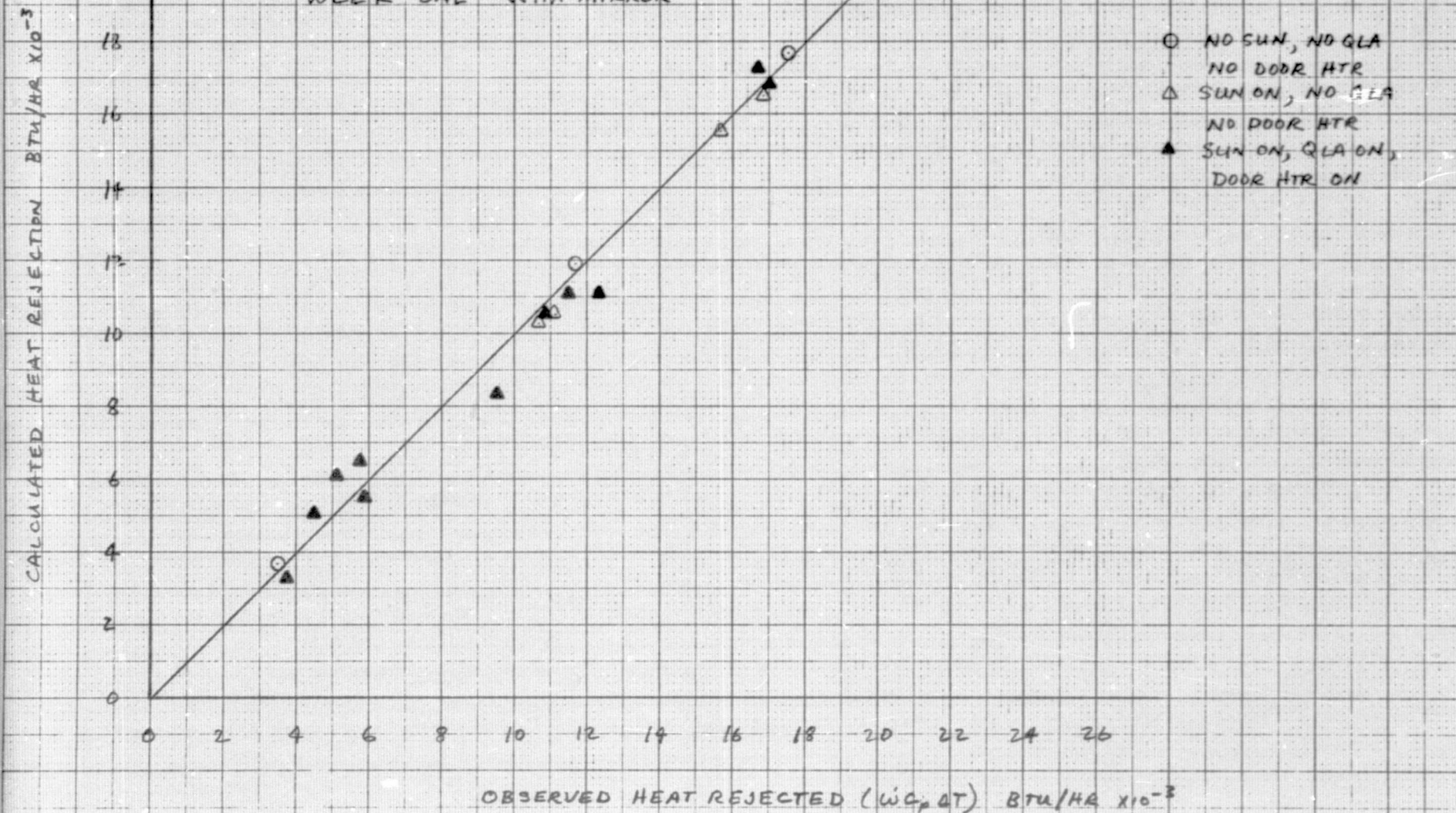
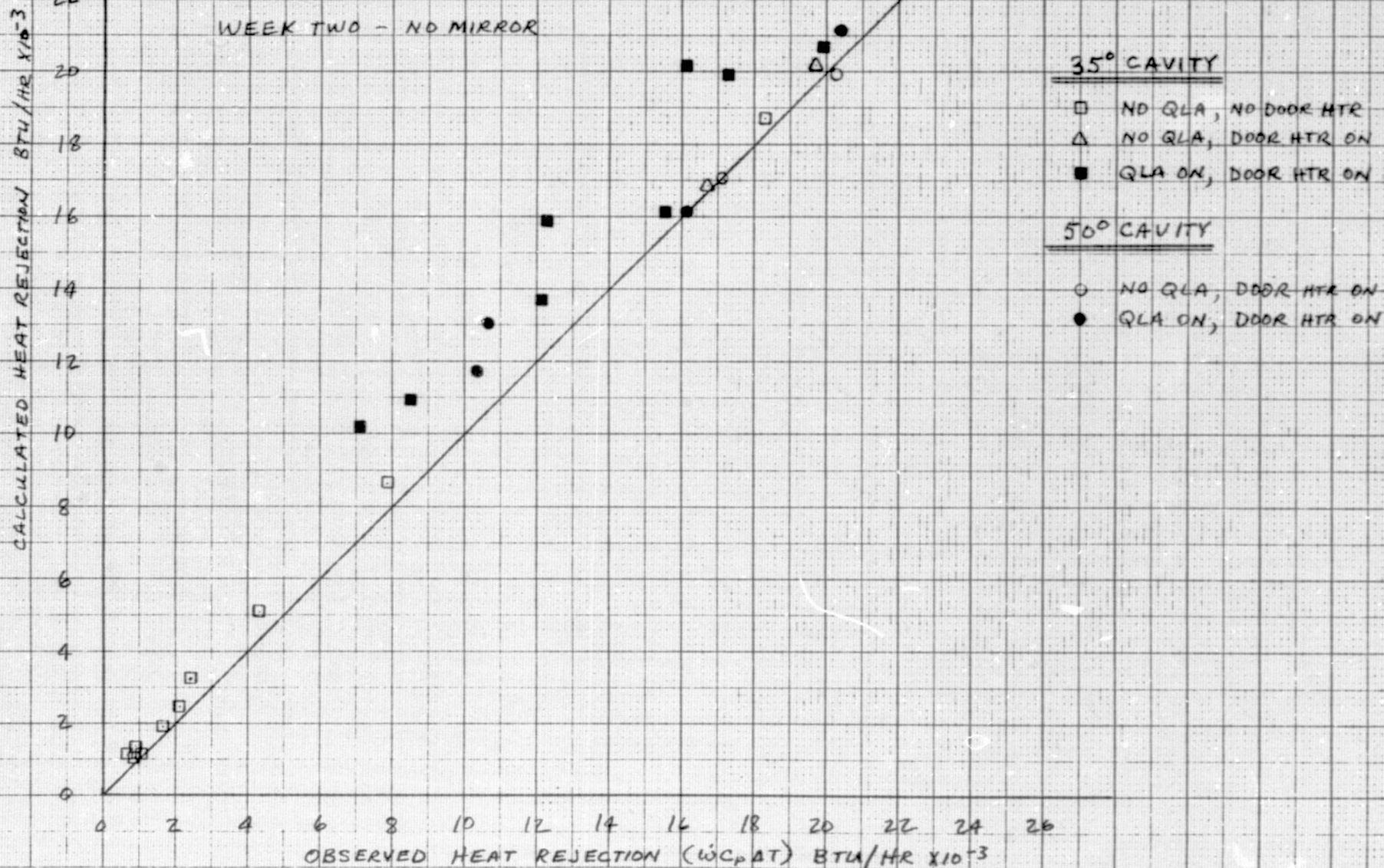


FIGURE 5-8A
CALCULATED VS OBSERVED
HEAT REJECTION
WEEK TWO - NO MIRROR



5.3 PERFORMANCE STUDIES

5.3.1 Maximum Heat Rejection

For any given environment, the heat rejection is maximized as inlet temperature and flow rate is increased. A sequence of test points was conducted to map panel heat rejection as a function of environmental and inlet conditions. Ultimately, such testing should result in extrapolated performance predictions for a full Shuttle 6 and 8 panel system. Only after such extrapolation can a comparison be made with Shuttle spec values, since these values are not given for an individual panel.

Table 5-8 summarizes high load test data for several test points. The difference between "desired" and "actual" absorbed environment was caused by unanticipated reflections off the LN_2 panels, as previously discussed. The actual environment is an estimate made using techniques discussed in previous sections.

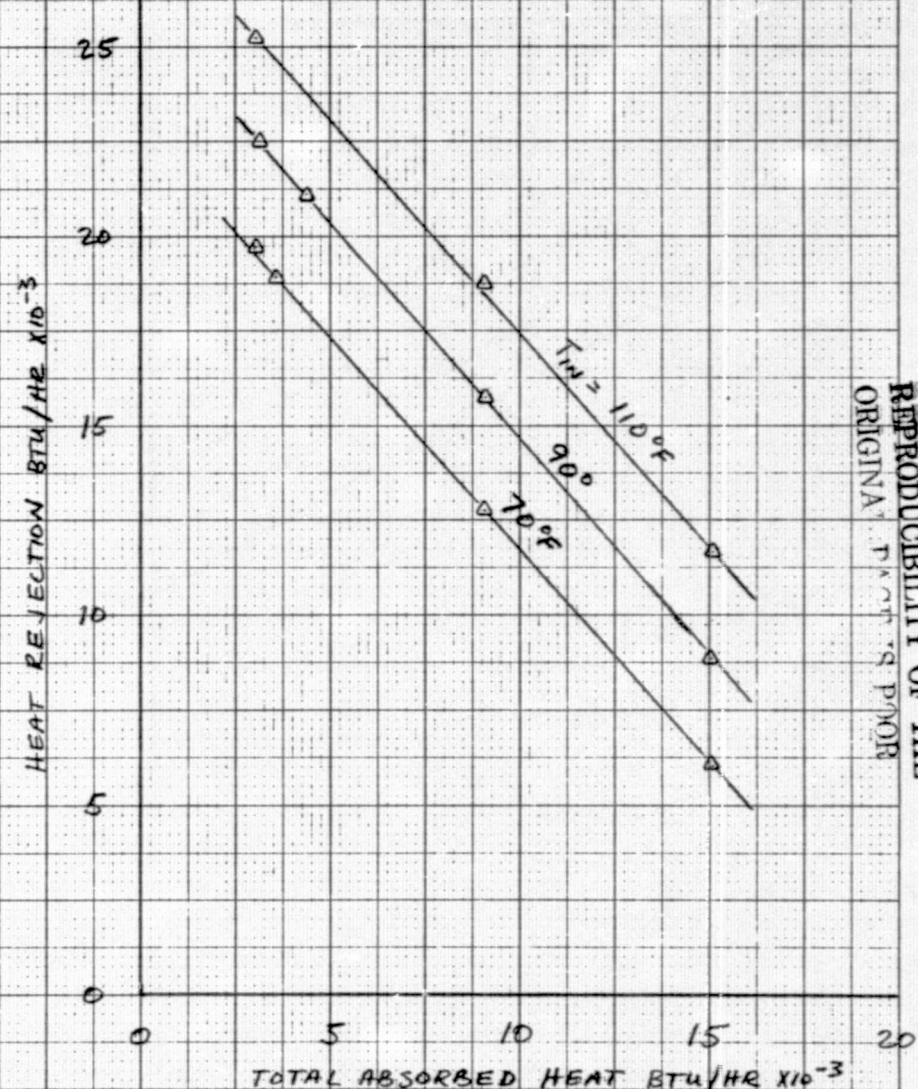
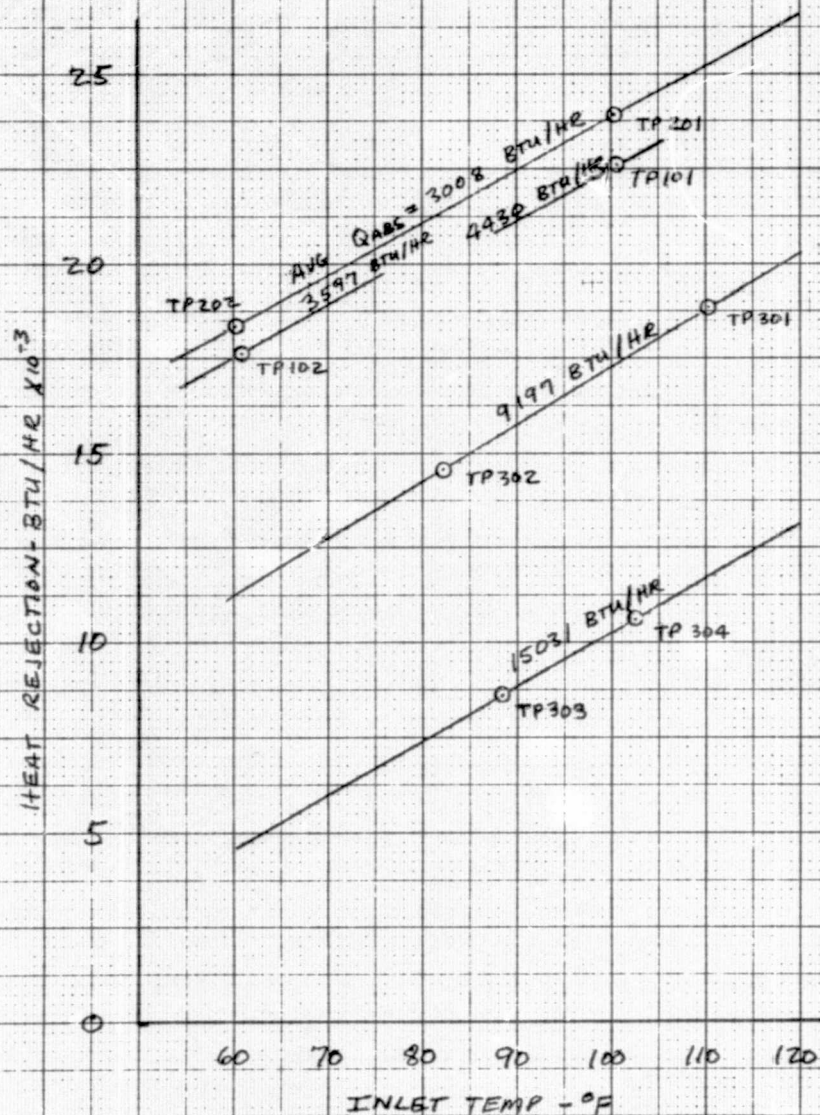
Figure 5-9 displays the heat rejection for the test panel plotted vs. inlet temperature with absorbed environment as a parameter, and a cross plot of rejected heat vs. environmental load. The latter plot enables extrapolation of performance to spec environments.

TABLE 5-8

HIGH LOAD PERFORMANCE RESULTS
B/L CAVITY DEPLOYMENT

TEST POINT	QIA NOMINAL SETTING	DESIRED TOTAL ABSORBED LOAD BTU/HR	DESIRED TOTAL ABSORBED LOAD BTU/HR	T _{in} °F	T _{out} °F	FLOW PPH	Q _{REJ} BTU/HR
201	0	0	3271	100.1	65.2	2759	23,935
202	0	0	2746	60.1	32.3	2699	18,311
301	40	6480	9367	110.1	80.0	2507	18,808
302	40	6480	9027	82.3	58.8	2513	14,594
303	80	12960	14,938	88.4	74.6	2500	8,576
304	80	12960	15,123	102.6	85.8	2540	10,654
101	0	0	4430	100.8	67.2	2699	22,545
102	0	0	3597	60.9	34.3	2699	17,533

FIGURE 5-9 HEAT REJECTION FOR RADIATOR PANEL
AT HIGH FLOW RATE



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FIGURE 5-10
HEAT REJECTION FOR RADIATOR
PANEL AT HIGH FLOW RATES

- WIDE CAVITY
- WEEK 2 / NO SUN

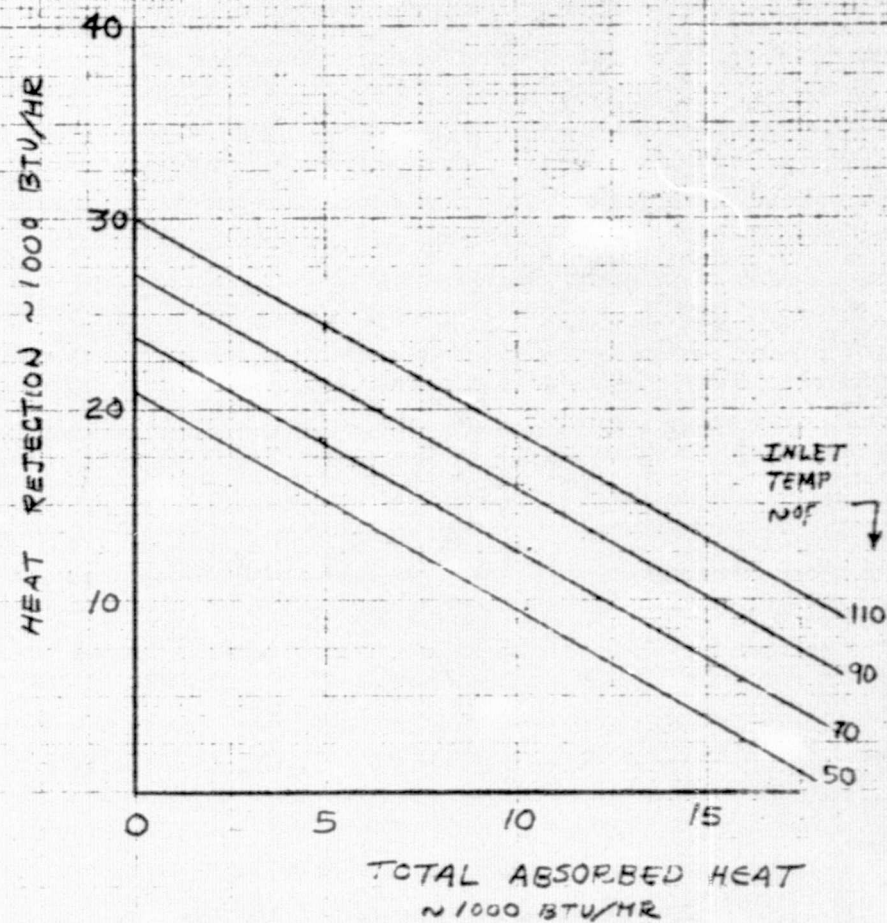
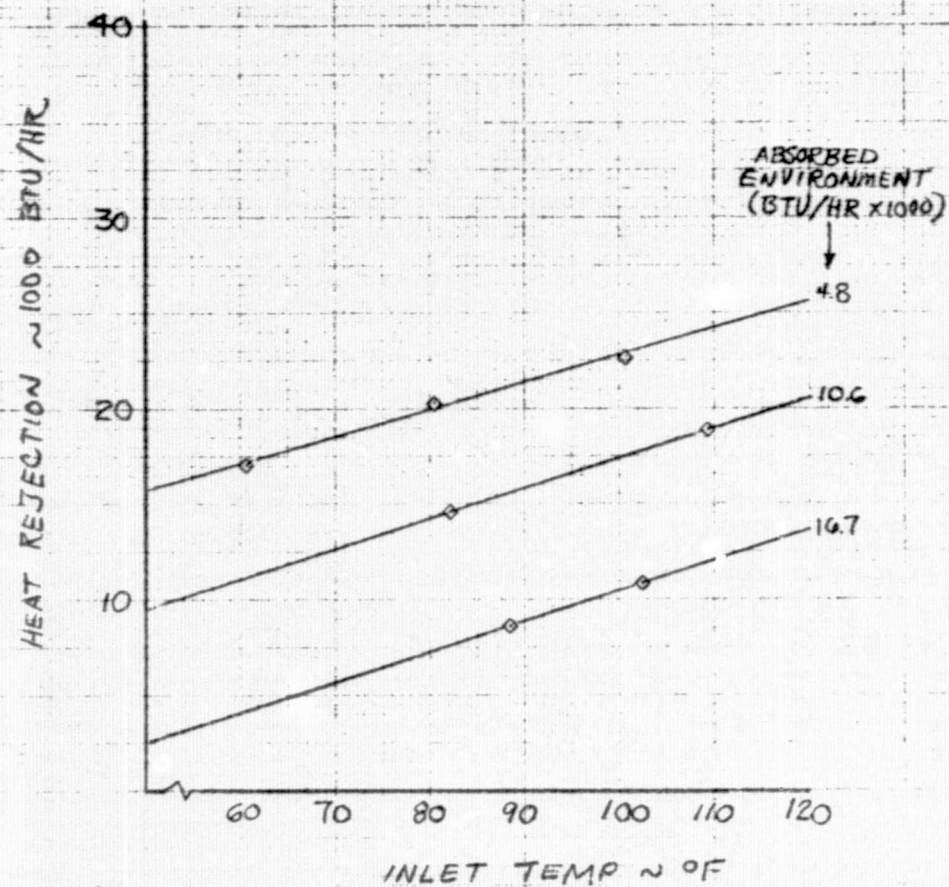


Fig 5-10 gives similar high load results for a wide cavity deployment angle.

5.3.2 Orbital Case Simulation

The difficulties encountered in maintaining a given orbital environment have been discussed in a previous section of this report. In particular, the unanticipated reflections from the LN_2 panel and the questionable radiometer readings during the test rendered the real-time adjustment of the environment extremely difficult.

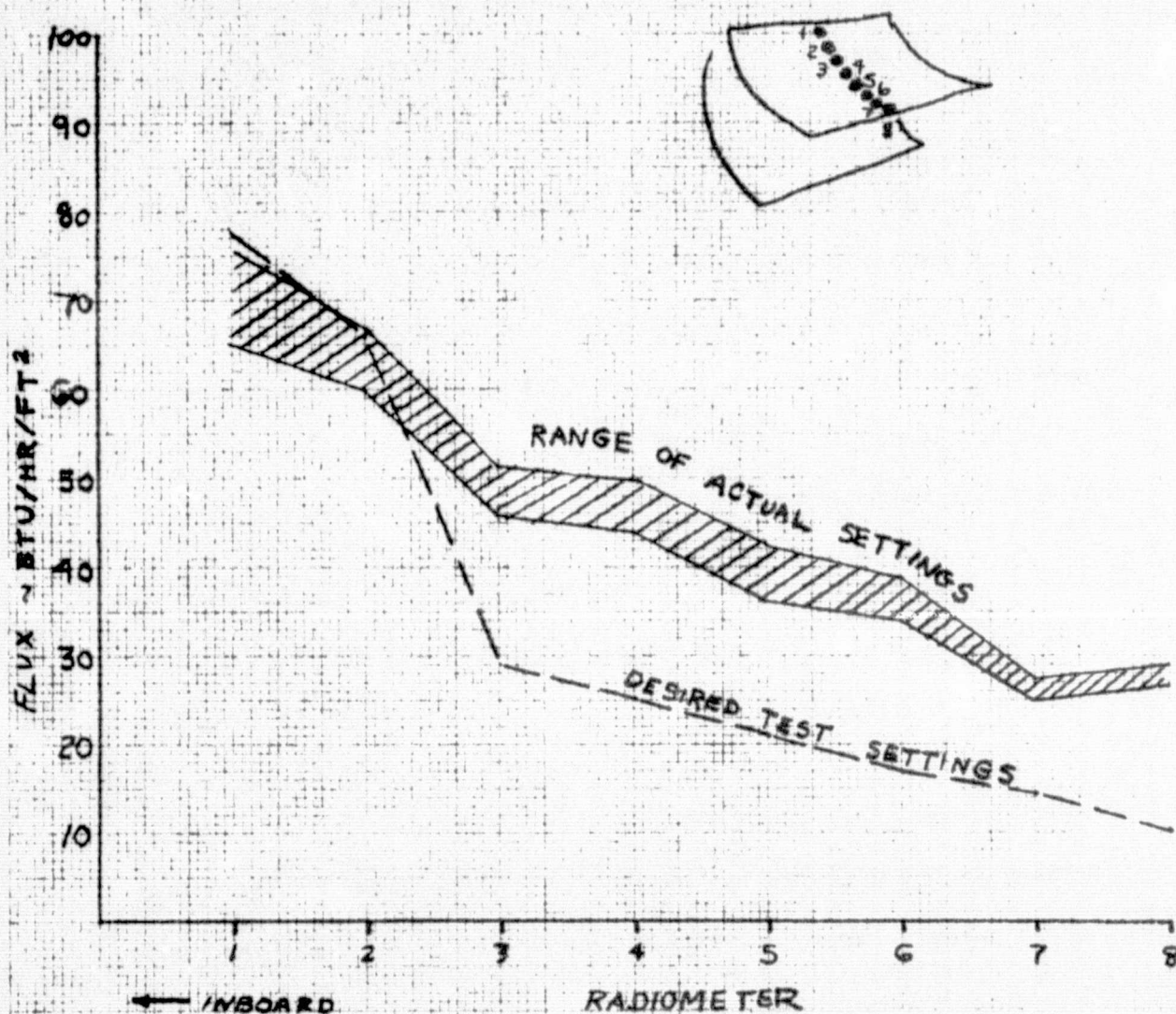
Fig 5-11 displays the environment desired to simulate a flight condition of $\beta=90^\circ$, roll= 167° , a situation which results in a 77° sun and the maximum hot environment on the panel. This desired environment was determined with a TRASYS simulation of earth-shine and albedo, and cavity assessment test results for sun on the top side of the panel. It is the solar impingement on the top side of the panel that causes the sharp inboard-edge peaking to occur.

Fig 5-11 also demonstrates the approximate actual environment that was achieved. It is obvious that (1) exact simulation of orbital environment was not achieved, but that (2) quantitative simulation of flight representative skew was accomplished. Thus, actual flight performance predictions are unavailable from the current testing, although confidence in the ability of the panel to stably operate under several inboard-to-outboard environment skews was enhanced.

Flight environments will, of course, not be steady. Thus, results from the current testing can be integrated into digital computer models to obtain transient profiles of system operating parameters.

FIGURE 5-11

DESIRED VS. ACTUAL FLUX ON
RADIATOR PANEL DURING
FLIGHT SIMULATION TESTING



5.3.3 Minimum Load Testing

A sequence of low load test points were conducted at both baseline 35.5 degree and 50 degree cavity orientations. Shuttle representative flows and inlet temperatures were determined real time through the use of a small system model programmed for the Hewlett-Packard desktop computer available in the Chamber B control room.

The environment estimated for the low load testing was in the range of 500 Btu/hr total absorbed by the panel. This is higher than the actual estimated Shuttle flight environment, due to the reflected energy from the chamber, as previously described. However, results should provide an estimate of typical Shuttle low load rejection capability.

Figures 5-12 and 5-13 display test results as outlet temperature vs. inlet temperature, for baseline and wide cavity, respectively. Flow rate varied from 140 lb/hr to 390 lb/hr and is a parameter of the two curves.

The right hand side of the two figures shows cross-plots of outlet temperature vs. flow rate with parametric variation in inlet temperature. Once inlet conditions to the two sided panels are known, these curves may be used iteratively to determine mid-forward and forward panel outlet temperatures. Once the forward panel outlet temperature is known, the mixed outlet temperature can be calculated, and the results compared with the desired (and controlled) mixed outlet temperature of 38°F. Differences are then fed back to the inlet as a change in flow rate, and the process is repeated.

FIGURE 5-12
LOW LOAD RESULTS - BASELINE CAVITY
 (TEST POINTS 207-213)

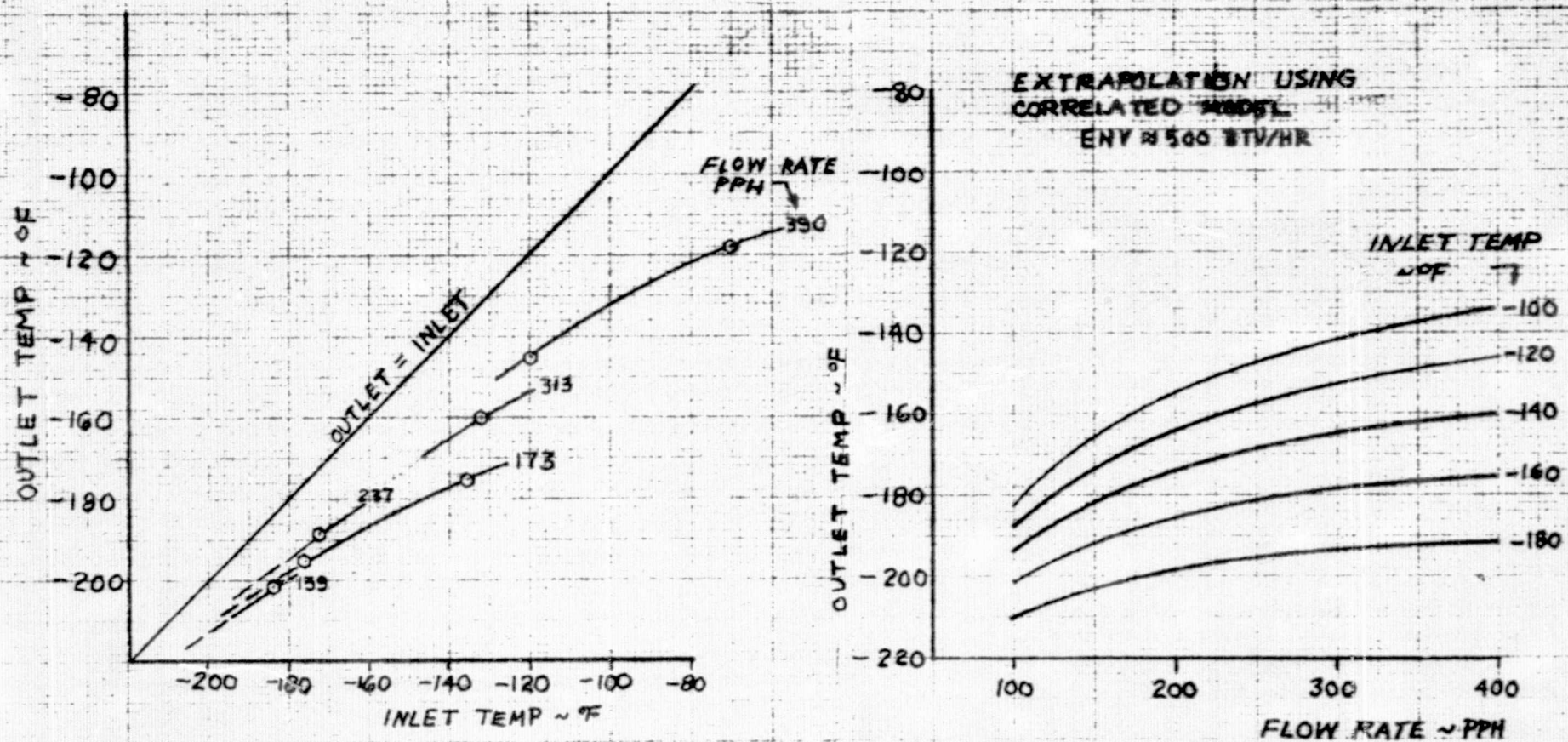
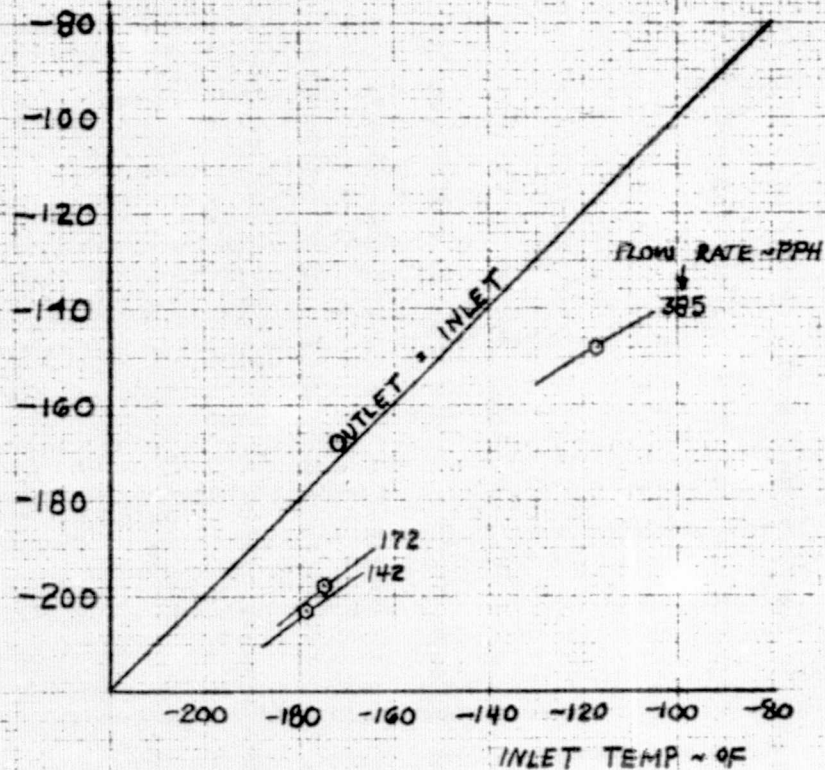
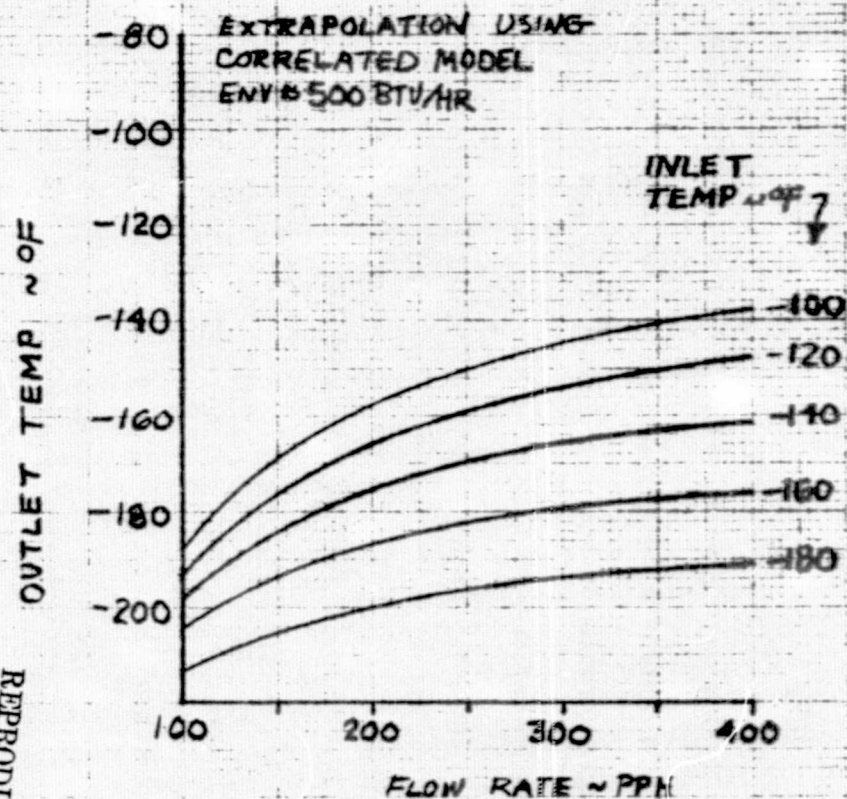


FIGURE 5-13
LOW LOAD TEST RESULTS - 50° CAVITY



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Alternatively, a system model can be correlated using the data shown, and then extended to predict system inlet conditions resulting in the desired minimum outlet temperature from the forward panel. The following table displays this type of system prediction for nominal and wide cavity angles, based on test data.

FORWARD PANEL OUTLET ~°F

SYSTEM INLET ~°F	BASELINE CAVITY		WIDE CAVITY	
	500 BTU/HR ENVIRONMENT	0 BTU/HR ENVIRONMENT	500 BTU/HR ENVIRONMENT	0 BTU/HR ENVIRONMENT
70	-136	-148	-144	-155
65	-152	-166	-160	-173
60	-170	-185	-177	-192
55	-190	-208	-196	-216
50	-211	-238	-217	-242

These predictions assume a mixed outlet of 37°F, 2700 lb/hr total flow rate through the system, and equal environment on each panel of a 4-panel series system.

The situation of 0 absorbed environment represents the "worst case" for potential panel freezing. By extrapolation of the tabulated data, it can be seen that to ensure a panel outlet greater than -196°F (which would represent a 15°F margin for error), the minimum system inlet temperature should be 58°F. This represents a heat load of 13,000 for the 4-panel system or 26,000 BTUH. for the 8-panel system.

5.3.4

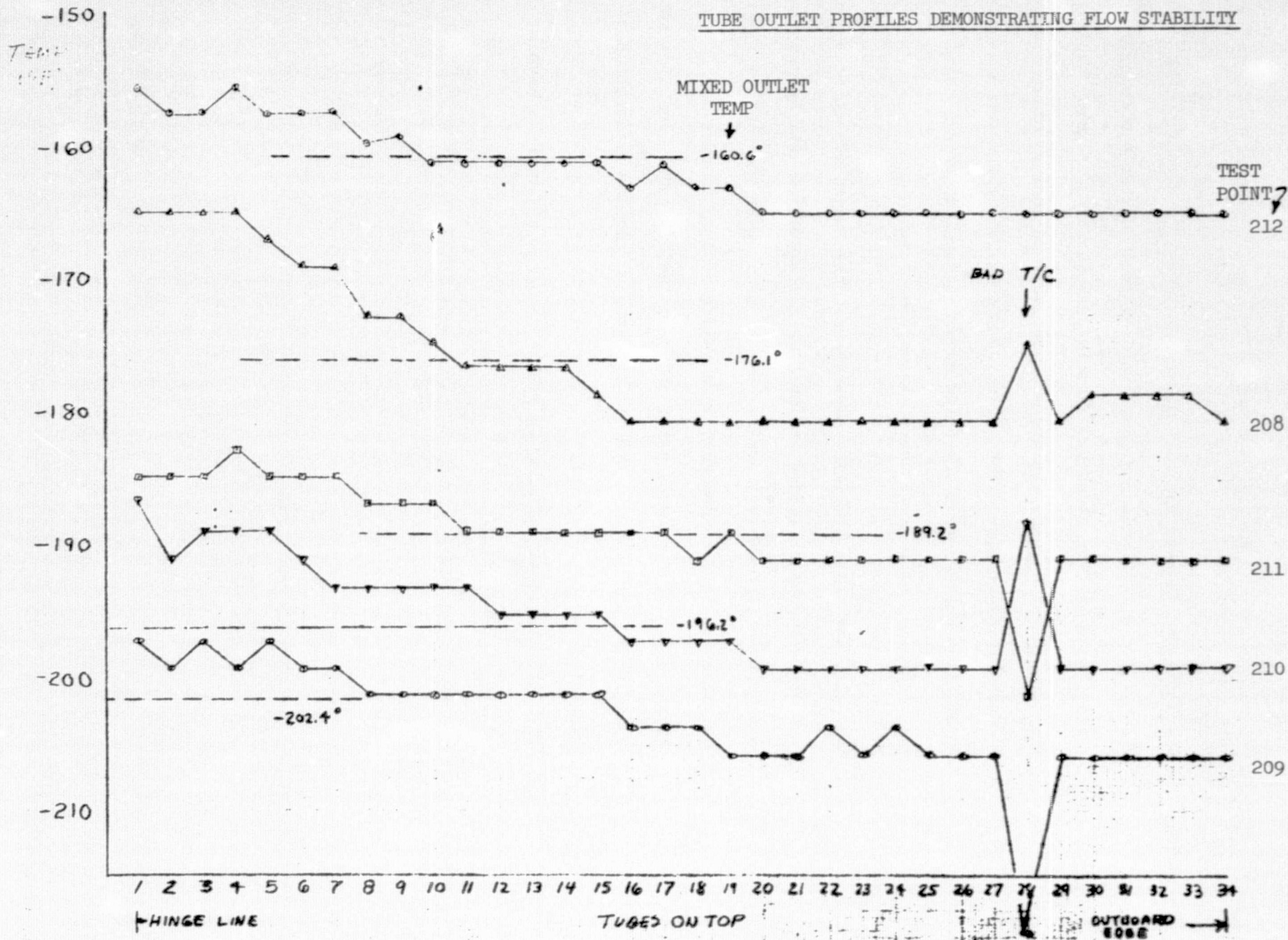
Stability Considerations

The ability of the radiator panel to operate in a stable mode over a wide range of conditions was clearly demonstrated. Figure 5-14 displays outlet temperature profiles for various test points, showing no unstable tendencies. The effect of gravity in disturbing a stable flow pattern (not a problem on-orbit, only in ground testing) was minimal as will be discussed in section 5.4.1.

The sole unresolved stability question relates to gravity effects on a one-sided panel tested in its proper orientation with respect to a horizontal two-sided panel. In the event that the panel qualification test is designed in such a way as to require the determination of a forward panel effect on an aft panel (and vice versa) by deploying them side by side at the proper relative orientation, the gravity instability question may still be relevant. However, all other questions relating to stable panel operation have been resolved favorably.

FIGURE 5-14

TUBE OUTLET PROFILES DEMONSTRATING FLOW STABILITY



5.4 DESIGN STUDIES

5.4.1 Effect of Payload Bay Door

The PBD generally causes an increase in the radiant flux incident on the panel. As expected the presence of the concave PBD results in a sharp focusing of solar radiation along the sixth and seventh tubes from the inboard edge. Fig. 5-15 shows this behavior. For certain test points with low inlet temperatures, these tubes were observed to exhibit a net absorption of heat, although for more typical high load conditions, these tubes did reject a small amount of heat.

The location of the "spike" at the 7th tube was somewhat unexpected based on cavity assessment test (CAT) results. In the earlier test, higher fluxes were measured further inboard. The cavity test was capable of distinguishing only average flux over an entire zone and thus, no exact maximum flux location could have been identified. It seems likely that very small variations in sun angle and deployment angle could have shifted the spike from a position slightly inboard of the CAT zone boundary, to a position slightly outboard of the boundary, where it was observed during I-tube testing.

With the sun off, the payload bay door caused the temperature profile on the panel to increase toward the hinge line. This characteristic is representative of the fact that inboard tubes have smaller views to space than do outboard tubes, and is augmented by the effect of the manifold on flow distribution. The characteristic slope of the tube outlet profile is due to both of these factors.

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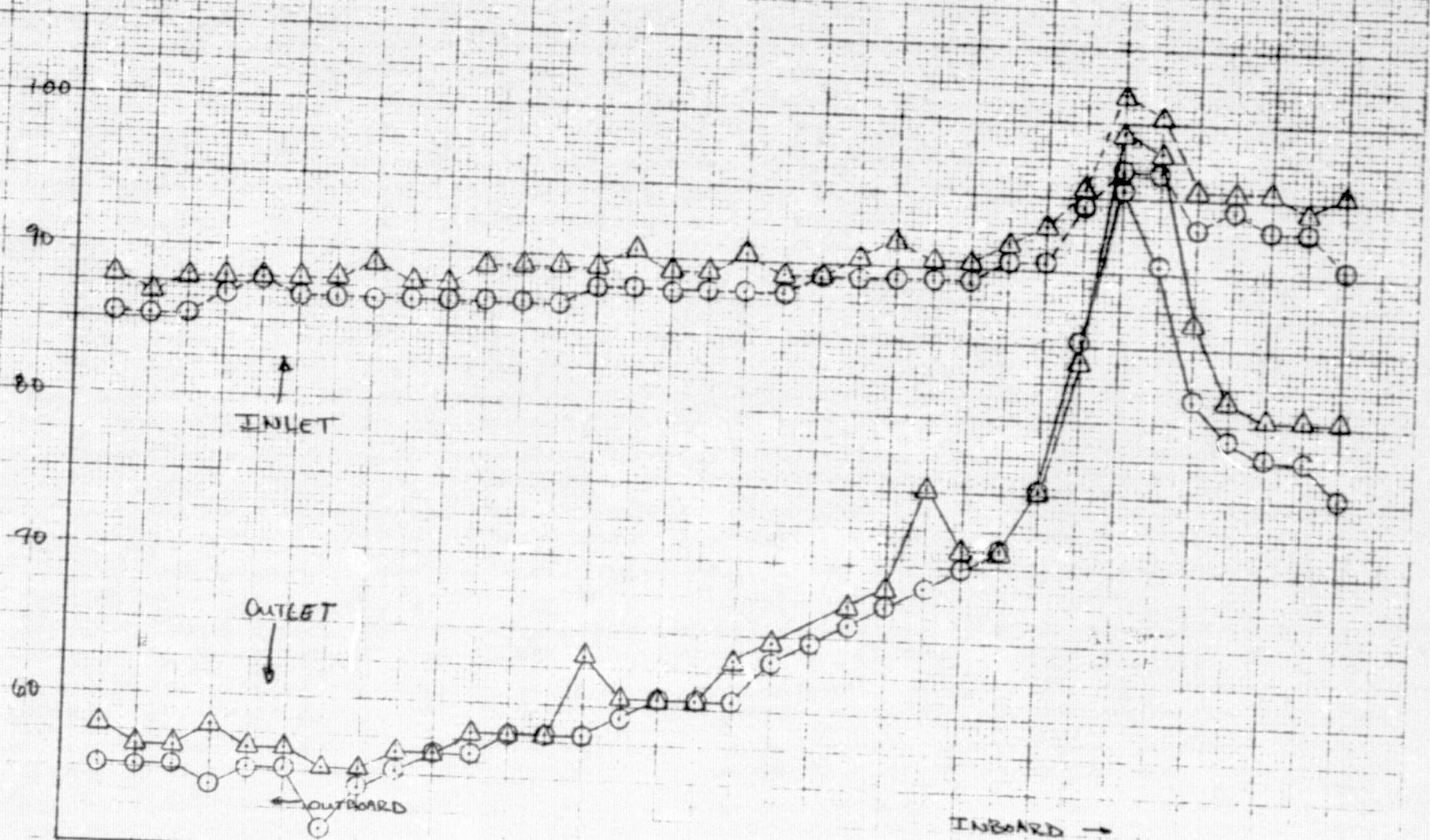
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TP 120

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FIGURE 5-15
 TUBE INLET/OUTLET PROFILE WITH SOLAR SPIKE



TUBE	TOP	BOT
47	87	85
45	86	84
43	87	85
41	87	86
39	87	86
37	87	86
35	87	86
33	87	86
31	87	86
29	87	86
27	87	86
25	87	86
23	87	86
21	87	86
19	87	86
17	87	86
15	87	86
13	87	86
11	98	94
9	95	91
7	92	88
5	91	87
3	90	86
2	88	84

The outboard-to-inboard increase in outlet temperature obscures the gravity effect observed in Dallas testing. This effect, although slight at high flow rates, caused lower temperatures at the outlet of the middle tubes, due to their lower position in the gravity field.

Test point 215 was intended to duplicate the Dallas test point 7, which was the most dramatic demonstration of a gravity effect.

Fig 5-16 compares these two test points. Again the effect of the payload bay door was to lessen the effect of the gravity skew.

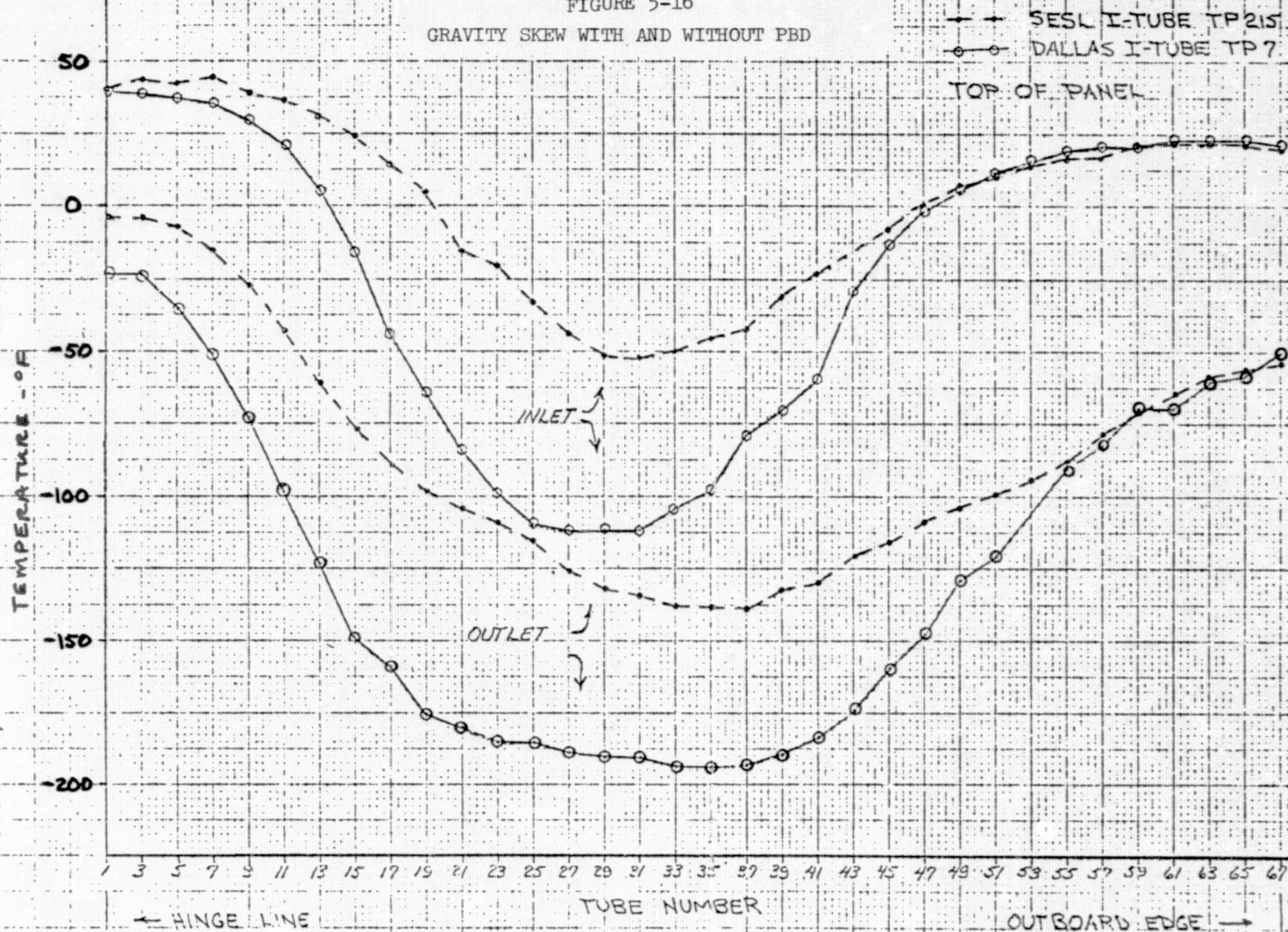
Since gravity skew is "driven" by the temperature difference between the inlet side and the outlet side of the panel, the door and the additional environment it generates, tends to reduce the driving force.

Fig 5-17 displays a comparison between the mixed panel outlet temperature and the coldest tube outlet temperature for a variety test points recorded both at Vought and at SESL. A relationship of this type will become important inflight since only mixed outlet will be available through telemetry data. With the door in place, no more than 3°F separated the coldest and mixed temperatures, less than the 10°F difference recorded without the door.

5.4.2 Fin Efficiency Determination

The determination of fin efficiency was made by using Leiblein's analysis technique and the 4 sets of intertube thermocouples installed for this purpose. Table 5-9 and Fig 5-18 show the results of this analysis, demonstrating that accurate determination of this parameter is difficult. A value of $\eta = .94$ was chosen by inspection of the data and is recommended for use in theoretical panel performance

FIGURE 5-16
GRAVITY SKEW WITH AND WITHOUT PBD



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FIGURE 5-17
COMPARISON OF MIXED OUTLET AND
LOWEST TUBE OUTLET FOR LOW LOAD
TEST POINTS

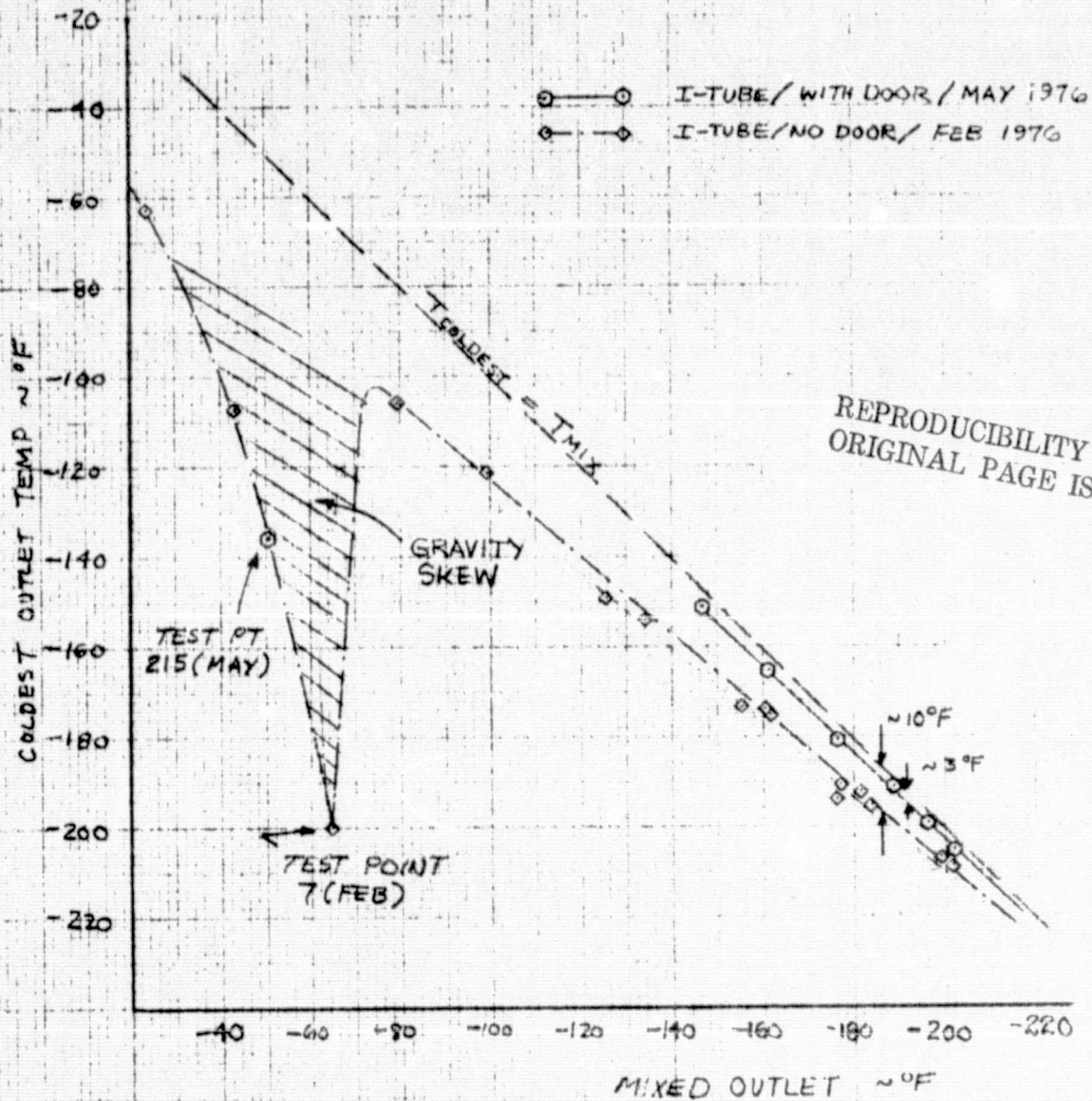
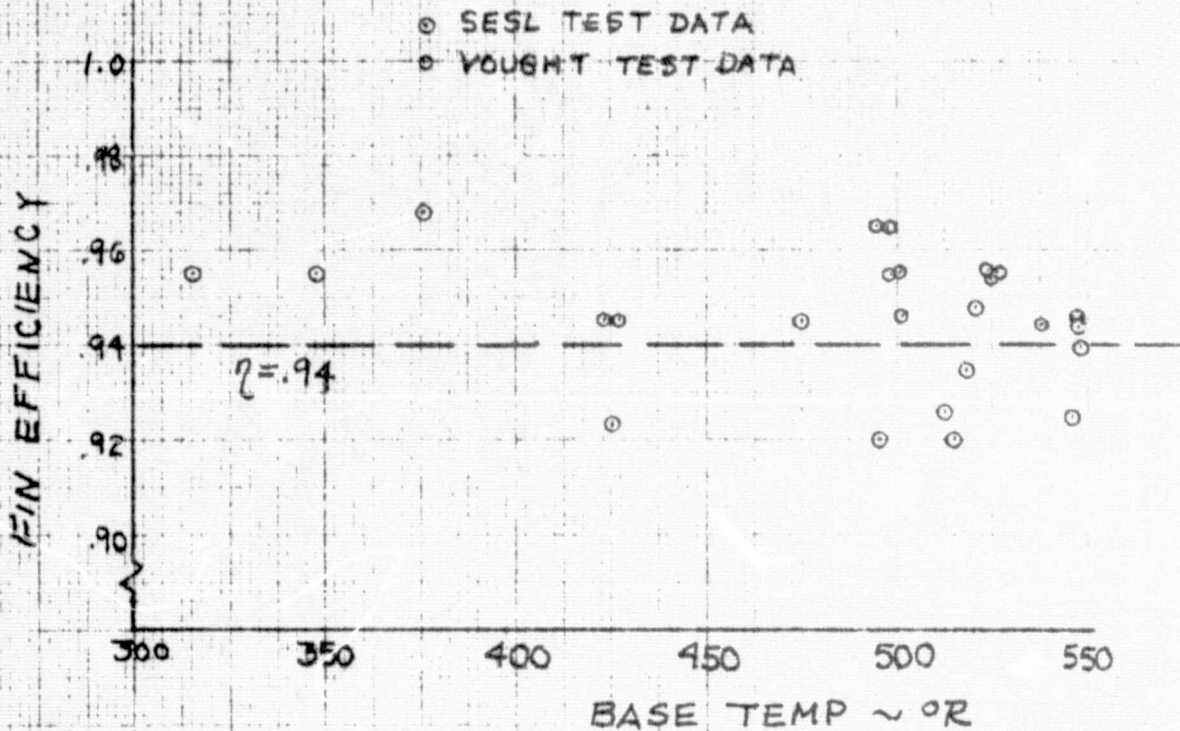


TABLE 5-9

FIN EFFICIENCY CALCULATION

TEST POINT	T_{base} (°R)	T_{low} (°R)	T_{sink} (°R)	$\frac{T_e - T_s}{T_b - T_s}$	$\frac{T_s}{T_o}$	L	η
201 inlet	547.5	538	369	.948	.67	.20	.944
201 outlet	517.5	509	369	.943	.71	.195	.946
101 inlet	548	539.5	385	.948	.70	.195	.946
101 outlet	519	510	385	.933	.74	.22	.935
118 outlet	495	489	445	.88	.90	.25	.92
208	314	310.5	250	.945	.80	.18	.955
207	374	370.5	255	.971	.68	.14	.968
207	347	343	255	.956	.73	.17	.955
120 inlet	547	540	444	.93	.81	.21	.94
120 outlet	515.5	508.5	444	.90	.86	.25	.92
105 outlet	546	539	474	.90	.87	.24	.925
108	512	505	450	.89	.88	.24	.925
113	429.5	426	397	.89	.92	.245	.922
130	476	469	340	.95	.71	.195	.945

FIGURE 5-18



predictions. All calculated values fell within $\pm 3\%$ of .94, and are thus acceptable with respect to experimental capability.

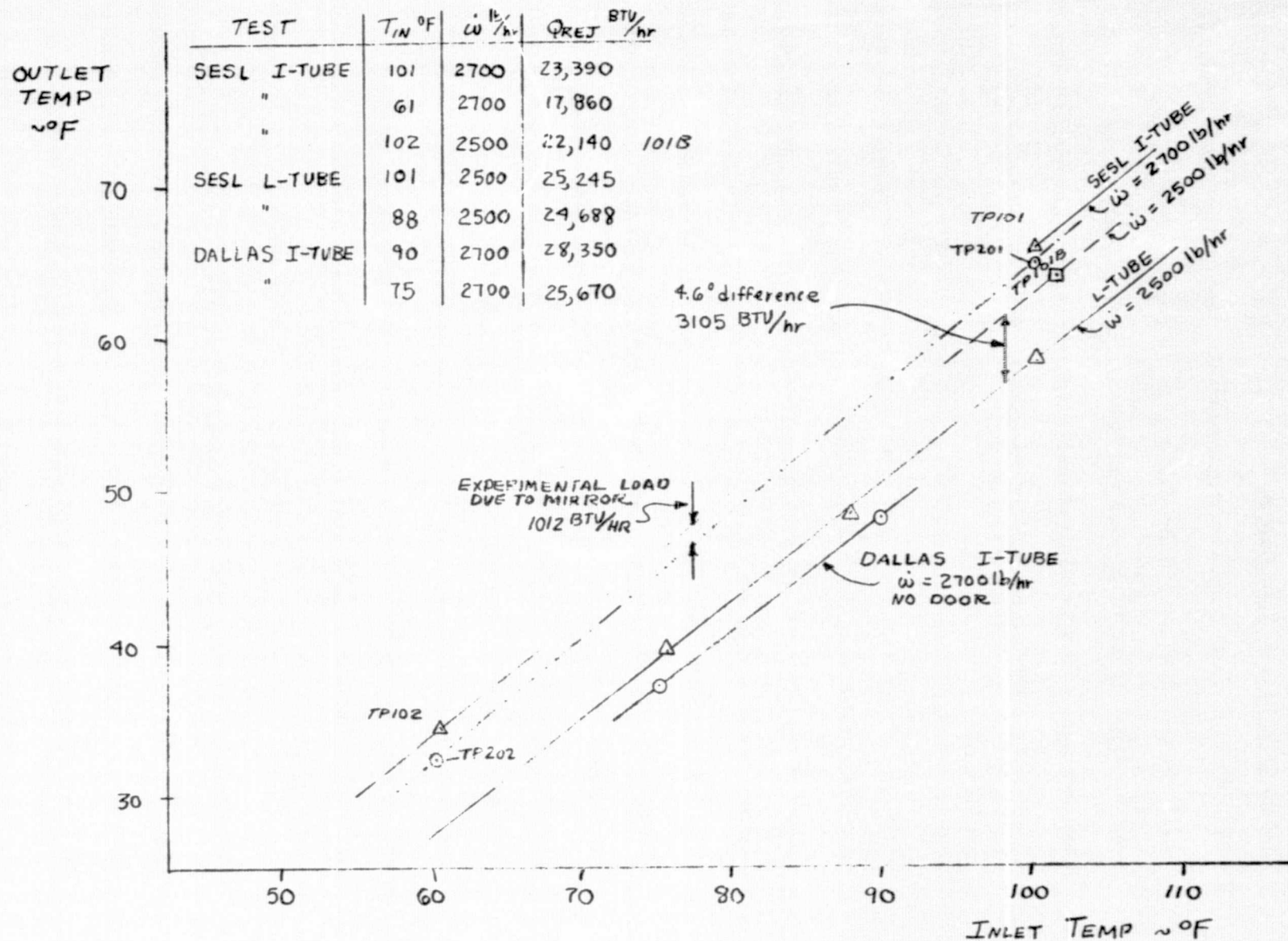
5.4.3 Comparison with L-Tube Design

By comparing test results with comparable test points run in August 1975 with a panel of L-tube design, it is concluded that there are no significant high load performance differences between the two designs. This result matches computer results generated by comparing SINDA models of I-tube and L-tube panels under identical environmental conditions.

A comparison of raw test data initially indicated a possible advantage for the L-tube over the I-tube panel. Figure 5-19 displays this comparison. However, by analyzing the amount of additional reflected energy caused by the LN_2 panel which was mounted above the I-tube panel (the L-tube panel "saw" only the quartz lamp structure and the top of Chamber A) the performance discrepancy was attributed to additional environment. Figure 5-20 displays data recorded by radiometers on the LN_2 panel looking toward the radiator, and by the two radiometers on the QLA looking upward toward the LN_2 panel. In Figure 5-21, the upper end of the radiometer response curve (for the radiometers on the QLA) is replotted, along with test data representing the difference between L-tube and I-tube results for 6 different test point pairs.

The results show that the performance difference is generally less than the absorbed radiation indicated by radiometers seeing reflections from the LN_2 panel. This reflection is the component of environment that was present in the I-tube test but absent in the L-tube test.

FIGURE 3-19

COMPARISON OF TEST RESULTS

BTU/HR/FT²

FIGURE 5-20
FLUX RECORDED ABOVE RADIATOR PANEL

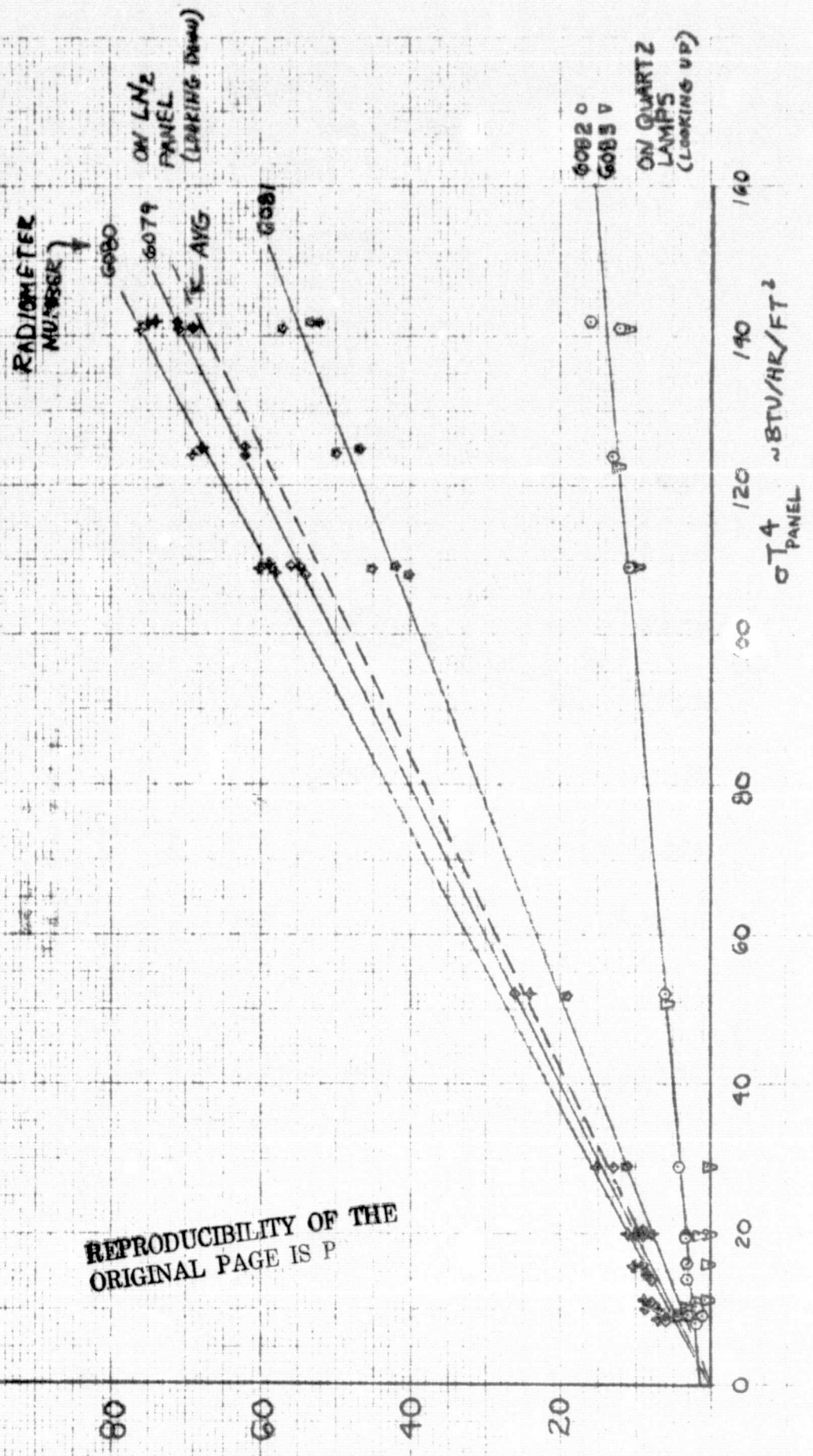
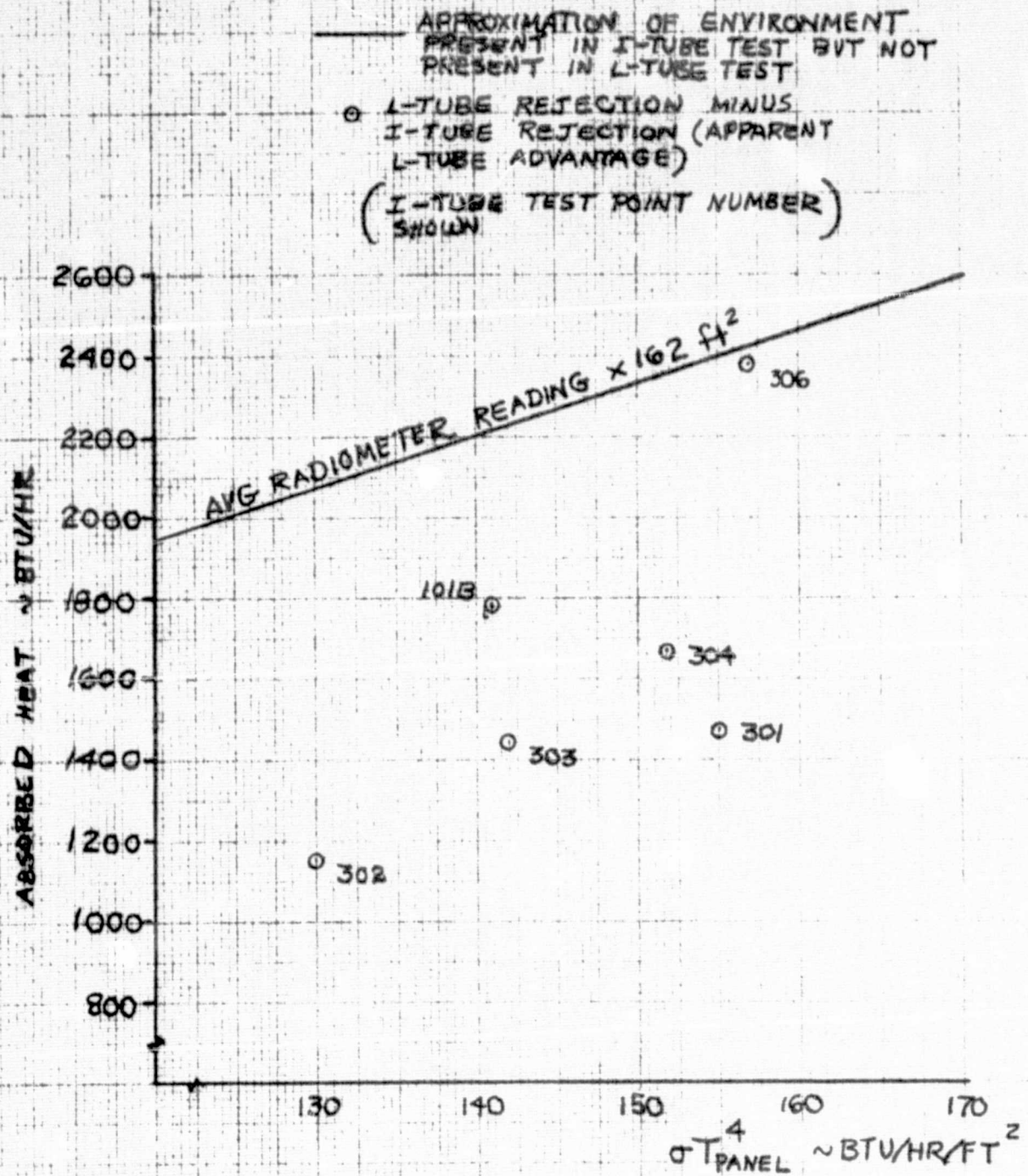


FIGURE 5-21
COMPARISON OF REFLECTED ENVIRONMENT
WITH I-TUBE/L-TUBE TEST RESULTS



The conclusion to be drawn is that there is no performance difference between I and L-tube designs at high load conditions.

5.4.4. Effect of Wide Cavity

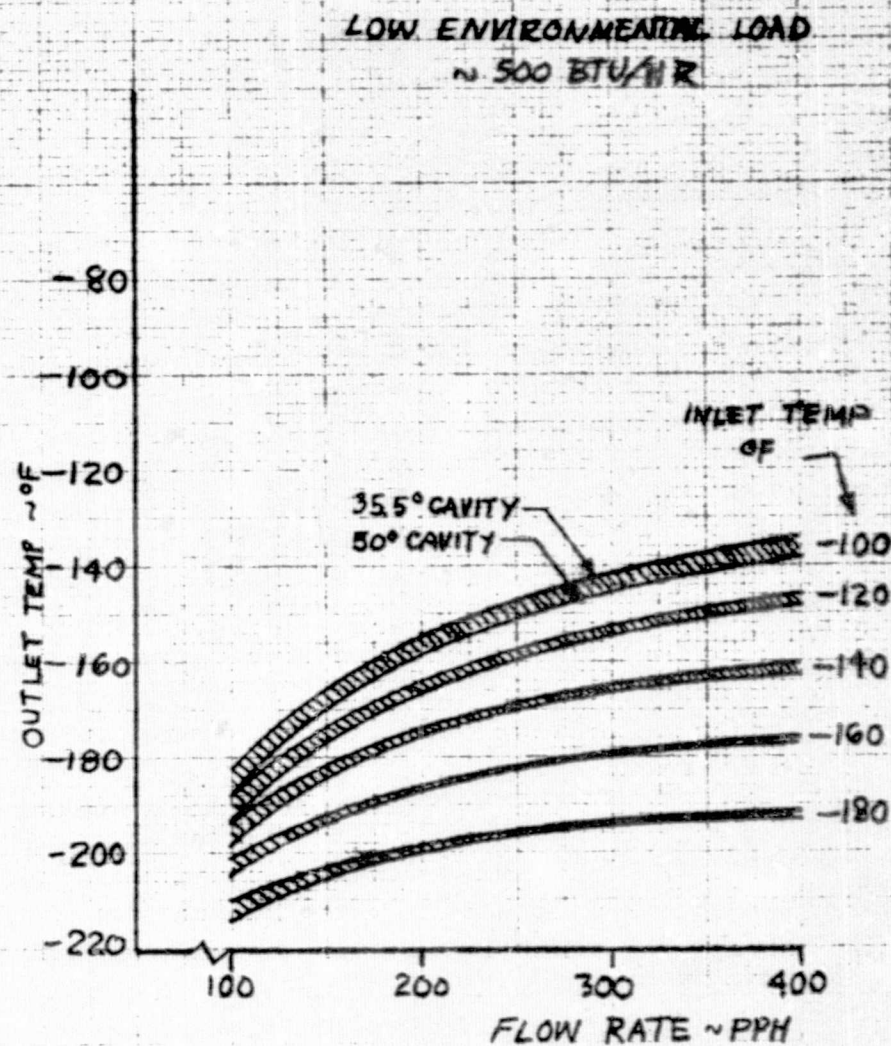
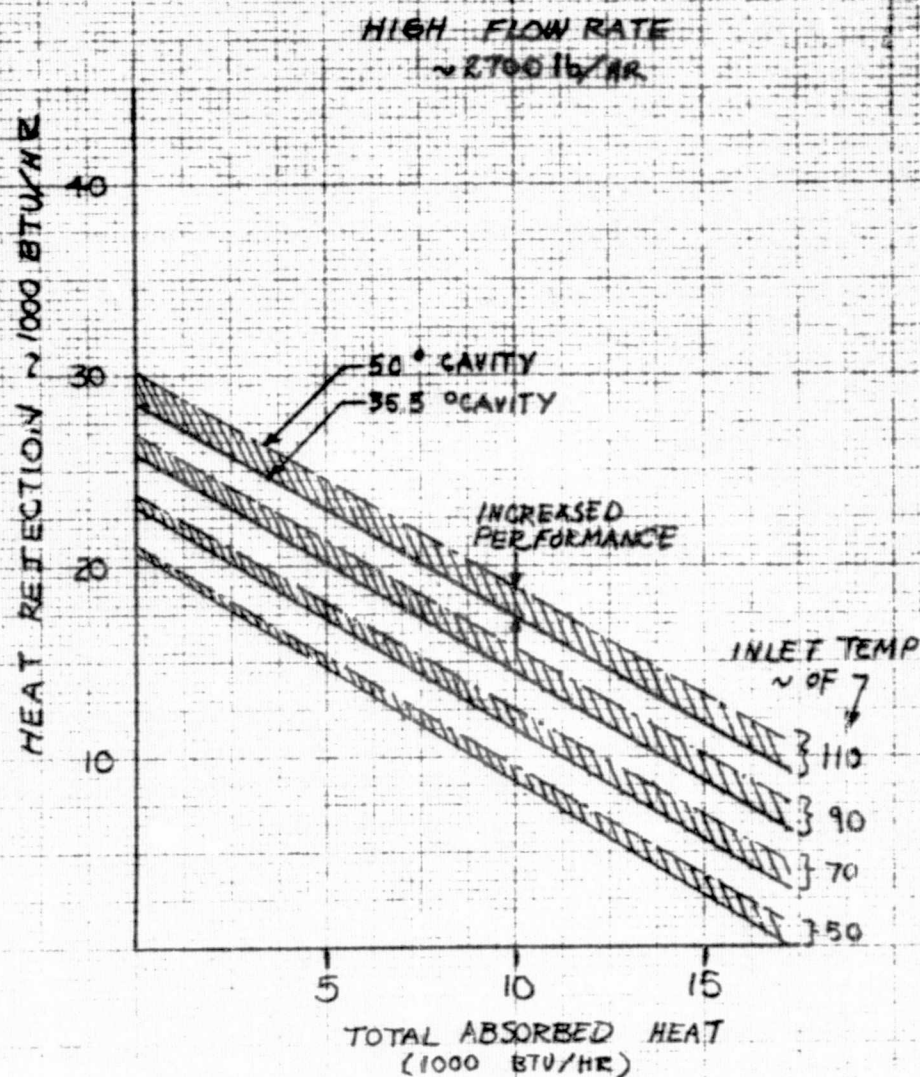
An estimation of the effect of increasing the cavity deployment angle was derived from the high and low load data presented in sections 5.3.1 and 5.3.3. These results are presented in Figure 5-22.

In the high load case, the important variable is the environment, and the desired result is stated in terms of performance improvement. Typical results show performance is improved by 1,000 to 1,500 Btu/hr by increasing the cavity angle from its baseline 35.5 degree deployment to a 50 degree deployment. These results are slightly misleading when it is recognized that changing the cavity angle will result in a slight change of environment. The proper method of making performance improvement predictions is thus to compare the 35 degree performance at the original environment to the 50 degree performance at the new environment. This task is best done with digital computer simulation after proper correlation with test results.

In the case of low load testing, environment is small and relatively constant, while flow rate is the important variable. At low load, outlet temperature rather than heat rejection is the key observable, due to the requirement that freezing be prevented. As can be seen, a 2°F decrease in outlet temperature is representative of probable performance over a range of possible inlet temperature and flow rates.

FIGURE 5-22

COMPARISON OF BASELINE AND WIDE CAVITY TEST RESULTS



6.0 CONCLUSIONS/RECOMMENDATIONS

Two weeks of thermal vacuum performance testing demonstrated that the I-tube panel can be expected to perform adequately on the Orbiter vehicle. From a mechanical standpoint, including silver-Teflon coating performance, the test panel was operated with no anomalies.

Confidence in the stable operation of the panel was enhanced by performance observations conducted throughout the range of likely environmental conditions. These included high and low, uniform and skewed, and solar and IR environmental simulation. The presence of the payload bay door induced a change in the panel temperature profile and generally masked the effect of gravity-induced instability, except in those test points specifically designed to exaggerate these effects. In all cases, the panel operated in stable flow regimes.

The only remaining instability question concerns a situation in which forward and aft panels are required to be ground-tested in their proper relative locations. Analytic simulation of gravity effects under these extreme conditions will be required before the full extent of this potential problem will be known.

Data was collected demonstrating that the high load capacity of the panel is consistent with pre-test predictions and panel design criteria, although a fin efficiency of .94 is recommended for future design studies. The I-tube panel performed equally with the L-tube panel at high loads, within the range of discrimination of the data-gathering apparatus and other

test constraints.

Sufficient data was collected to allow correlation of analytic models of the panel so that system performance can be predicted with added confidence. Such predictions will extend the range of environmental simulation to true orbital(transient) situations.

The minimum required low load for an 8-panel system was extrapolated to be 26,000 BTU/hr assuming evaporator off and 15⁰F safety factor in mixed outlet temperature. Increasing the cavity deployment angle to 50⁰ increases this minimum low load to 27,300 BTU/hr. Sufficient data is available to allow extrapolation of these results to other situations, such as 6-panel configurations, and higher mixing valve set-point.

At high loads, increasing the cavity deployment angle from 35.5 to 50⁰ was shown to increase heat rejection by 1,000 to 1,500 BTU/hr, depending on conditions. With the sun in the cavity, these results should be considered only tentative, and an effort made to confirm them with correlated analytic models. The total system advantage of an increased deployment angle cannot be directly extrapolated from test data, but test data should improve the predictive power of the models.

It is recommended that further testing of this type be characterized by an increased emphasis on a thorough understanding of chamber environment and environmental measuring techniques. The uncertainty in the environment was satisfactorily resolved post-test, but the real-time confusion caused a preoccupation by the test team on this problem and probably prevented other opportunities for additional data.